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WATER AND AGRICULTURAL DEVELOPMENT IN ETHIOPIA: AN ECONOMIC ANALYSIS OF POTENTIAL RETURNS TO PUBLIC INVESTMENT IN AGRICULTURAL WATER PROJECTS

by

 YILMA TEKLEMARIAM

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled "Water and Agricultural Development in Ethiopia: An Economic Analysis of Potential Returns to Public Investment in Agricultural Water Projects" submitted by Yilma Teklemariam in partial fulfilment of the requirements for the degree of Doctor of Philosophy.

ABSTRACT

The primary objective of this study was to examine the economic feasibility of agricultural water projects specifically designed to expand foodgrain production and labor employment in Ethiopia.

The nature, magnitude and implications of the food and unemployment problems in Ethiopia are analyzed in some detail. The role public investment can play in developing and making water available for a range of agricultural purposes including irrigation, livestock water supply and rural household water supply is examined both theoretically and empirically. Neoclassical theory of production and public investment theory provided the theoretical underpinnings of the study. Recursive programming and benefit-cost analysis were employed to conduct the empirical analysis. Data were analyzed for representative areas of the two major agro-climatic regions of Ethiopia.

The first project area is the Megech River area located in the Abay River Basin. It encompasses 5,890 hectares of irrigable land. This area was selected to represent the highland regions of Ethiopia. The initial capital requirement of this project was estimated at E $2.1 million (1970 dollars) with E $1.4 million being required annually over the first ten year expansion period. The

economic feasibility of this project was analyzed under three different strategies. Under its most desirable strategy, the Megech Project yields an internal rate of return of 17 percent over a 40 year planning horizon. The project will break-even at the end of the sixth year. Cash flow discounted at 10 percent shows that the project has a pay-off period of 14 years.

After full development, the Megech Project could produce an estimated 22,975 tons of foodgrain annually, roughly a two-fold increase over the annual level of production that would be expected under improved practices without the project. The direct permanent employment effect of the Megech Project is estimated at 4,672 persons as compared to 4,493 persons under improved practices without the project.

The second project area is the Kesem River area located in the semi-arid plains of the Middle Awash Valley. The project area covers 5,650 hectares of irrigable land. The initial capital requirement of this project is estimated at E $2.4 million. About E $1.0 million would be required in annual capital outlay during the first ten year expansion period.

Analysis of the rate of return shows that the Kesem Project has an internal rate of return of 27 percent over a 40 year planning horizon. The project will break-even at

the end of the fifth year. Cash flow analysis discounted at 10 percent indicates that this project has a pay-back period of 11 years. The successful implementation of this project can add up to 24,577 tons of foodgrain to the nation's food supply annually. It also has the potential to generate direct permanent employment for approximately 4,499 persons. In addition, both projects have wide ranging impacts on balance of payments, interindustry linkages, capital accumulation and general social welfare.

The major policy implication of the study is that agricultural water development should be an integral part of agricultural and rural development planning in Ethiopia. In this respect, not only should government investment policy emphasize irrigation and rural water supply development but incentives and various forms of inducement should be provided to community groups to conserve, develop and manage efficiently the watersheds in which they live.

It is emphasized that before implementing a broad policy of water development, it is essential to improve and strengthen water institutions at all levels including local, regional and national. The study further recommends that small pilot projects be launched to test the practical feasibility of the proposed projects as a step toward the formulation of realistic national policies and programs in the water resources field.

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CHAPTER I

INTRODUCTION

In this study an attempt has been made to investigate the contribution of water development to the expansion of agricultural output and rural labor employment in Ethiopia. More specifically, efforts have been made to determine the economic feasibility and potential impact on food production and employment of selected agricultural water projects in Ethiopia. In this chapter an attempt is made to put the problem in its proper perspective by providing essential background information and briefly outlining the nature and scope of the study.

Background to the Problem

A characteristic feature of the Ethiopian economy is its heavy dependence on traditional agriculture. Although recent years have witnessed the emergence of a modern sector, peasant agricultural production still forms the largest sector of economic activity in the country.

Ethiopia's real Gross Domestic Product (GDP at con-

stant factor cost of 1961)[1] rose from approximately E $2.32 billion in 1961 to E $3.45 billion in 1970,[2] thus registering an average annual growth rate of 4 percent over the ten year period (Appendix A, Table A.1). Agricultural GDP increased at an average annual rate of 2 percent, up from approximately E $1.50 billion to E $1.83 billion over the same period.

In sharp contrast to the agricultural sector, the non-agricultural sectors showed steadily increasing growth trends, with practically all of them registering average annual growth rates of 6 percent or higher between 1961 and 1970 (Appendix A, Table A.1). Consequently, the annual share of agriculture in the GDP steadily declined from 64.8 percent in 1961 to 53.1 percent in 1970, suggesting the emergence of a structural shift in the economy. Despite the decline in the share of agriculture in the GDP in the 1960's, employment in agriculture remained relatively unchanged at around 88 percent of the active labor force (Appendix A, Table A.2). During the same period, population increased at an average annual rate of 1.9 percent; and

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[1] According to the Central Statistical Office, Gross Domestic Product at factor cost is less than Gross Domestic Product at market prices by the amount equal to the difference between indirect taxes and subsidies. Imperial Ethiopian Government, Central Statistical Office, Ethiopia: Statistical Abstract, 1972 (Addis Ababa: Central Statistical Office, 1972), p. 117.

[2] In 1976 exchange rate, E $1.00 = U.S. $0.50.

national per capita income increased at an average annual rate of 2.1 percent, up from E $110.6 in 1961 to E $136.2 in 1970.

Within the agricultural sector itself, crop and livestock production account for the largest share of the output, while forestry, hunting and fishing play only a minor role. In 1970, about 94.5 percent of agricultural production consisted of crop and livestock output. The rest was made up of forestry (5.2 percent), hunting (0.1 percent), and fishing (0.2 percent) (Appendix A, Table A.1). Hunting has become a negligible activity, while forestry and fishing have shown only slight increases in importance over the past decade. The value of crop and livestock output, on the other hand, increased at an annual average rate of 1.9 percent, increasing from E $1.43 billion in 1961 to E $1.73 billion in 1970. Nevertheless, the relative share of crop and livestock output in the GDP declined from 61.8 percent in 1961 to 50.2 percent in 1970.

Presently, the crop and livestock sector is the major source of livelihood for a significant proportion of the population. It is estimated that close to 90 percent of the population lives in the rural areas and is engaged, directly or indirectly, in crop and livestock raising.

Judging from the past performance of the Ethiopian economy, the employment structure is unlikely to change significantly in the foreseeable future. The agricultural sector, therefore, must continue to provide employment and

a means of livelihood for increasing numbers of people in the 1980's and 1990's. This, however, is not to say that the existing labor force is fully employed. Although official unemployment figures are unavailable, it is widely believed that significant unemployment and underemployment exist in Ethiopia.[1] The unemployment problem can be expected to worsen if the population surges upwards at the estimated annual rate of 2.5 percent[2] in the late 1970's and 1980's. The fact that the population is disproportionately distributed between the urban and rural areas also means that most of the population pressure will be felt in the rural areas. However, the towns will not be spared the onslaught as scarcity of opportunities in rural areas forces mass migration to the cities. The urban population is currently expanding at an annual rate of about 6.6 percent, of which 4 percent is believed to be due to net in-migration from the rural areas.[3] In view of the foregoing, it is clear that in the foreseeable future only rapid expansion in rural development can provide relief to the unemployment

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[1] For a broader discussion of the unemployment problem in Ethiopia, see Yilma Teklemariam, "Issues in Labor Unemployment and Migration in Ethiopia" (Unpublished paper, University of Alberta, Department of Agricultural Economics, Edmonton, 1973).

[2] Imperial Ethiopian Government, Central Statistical Office, Ethiopia: Statistical Abstract, 1972, op. cit., p. 20.

[3] Ibid.

problem in Ethiopia.

The contribution of the agricultural sector to the Ethiopian economy as a whole, is not only restricted to providing a means of livelihood for the great majority of the population, important as this function is. Farm commodities account for over 95 percent of Ethiopia's exports, with coffee alone accounting for about 60 percent of the foreign exchange earnings (Appendix A, Table A.3). The agricultural sector also plays a vital role in providing the raw material base for most of Ethiopia's manufacturing industry. In 1970, for instance, about 75.9 percent of the gross value of production in the manufacturing sector originated in agricultural processing industries which included food, beverage, tobacco, textile, leather and wood industries.[1] During the same year, these industries employed 79.2 percent of the industrial labor force.[2]

The single most important contribution of Ethiopian agriculture to national welfare, however, is the provision of domestic food supply. The domestic production of adequate food supplies is of crucial importance for Ethiopia. Because scarcity of foreign exchange severely limits Ethiopia's capacity to augment her domestic food supply with substantial imports from abroad, practically all of the national

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[1] Ibid., pp. 56-57.

[2] Ibid.

food supply requirements must be produced at home. Ethiopian agriculture, therefore, has the huge task of adequately feeding a rapidly expanding population. Unfortunately, as events in recent years have shown, this task has proven to be exceedingly difficult. If past records are any indication, Ethiopian agriculture, unless effectively mobilized, is unlikely to meet satisfactorily the challenge of feeding an expanding population.

The Problem

Per capita food output in Ethiopia increased only slightly between 1964 and 1972 (Appendix A, Table A.4). Per capita production of calories and proteins increased by approximately 3 percent between 1964 and 1971, an average increase of less than 0.4 percent per year. Although very crude indicators of national nutritional intakes, various food balance studies carried out between 1958 and 1971 seem to show that per capita nutritional intake in Ethiopia has in fact been declining over the past decade (Appendix A, Table A.5). Furthermore, food production and requirement projections based on trend rates of growth seem to indicate that the mere continuation of past production trends will not be sufficient to meet the expected level of food requirements.[1] Evidence of food scarcity in Ethiopia

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[1] For a detailed discussion of Ethiopia's food problem see Appendix A.

has already shown itself in soaring food prices and acute regional shortages since the early 1970's. Given the projected rate of population growth of between 2 and 2.5 percent in the late 1970's and 1980's, it appears that the country will experience a period of prolonged food crises unless substantial investment is made to boost food production in the shortest possible time. Accordingly, the problem of how to increase food production in a reasonably short period of time is of fundamental importance to Ethiopia.

While the food problem stands out as the problem of highest national priority in Ethiopia, the problem of providing employment for the rapidly increasing labor force seems to be equally urgent. As has been pointed out, there is widespread unemployment and underemployment in Ethiopia. Furthermore, the unemployment rate may be expected to rise with expected increases in population. The food and unemployment problems in Ethiopia, therefore, constitute the "twin" problems that require urgent corrective action if the well-being of the Ethiopian people is to be improved.

This study attempts to focus on these two problems. More specifically, it seeks to examine whether public investment in relatively simple agricultural water projects represents an economically feasible means of expanding food production and employment.

Purpose and Scope of the Study

Unlike many countries and regions sharing considerable climatic similarities, Ethiopia has virtually neglected irrigation development as a means of increasing food production and employment. The existing food production system depends almost entirely on dryland farming. But the extremely uneven seasonal and regional distribution of rainfall and its wide interannual variability casts serious doubts whether the present dryland farming system can be adequately developed to meet the rapidly rising demand for food and fiber.

In addition to food shortages, Ethiopia currently suffers from water stress. Under existing practices, farm water supply usually comes from undeveloped surface sources and it is common for farm families to travel considerable distances every day to water their stock and draw supplies for household use. In times of drought, which is not uncommon in parts of Ethiopia, water scarcity often results in great disasters, as witnessed in 1973. The prevailing food and water crises in Ethiopia, therefore, underscore the urgent need for directing attention to water resource development.

Provision of sufficient quantities of water for Ethiopian agriculture requires a considerable amount of investment. Externalities and other public good characteristics associated with water projects render investment in

such projects unattractive to private investors. It therefore becomes the responsibility of government or an authorized public agency to develop and make available water resources for irrigation and other farm uses.

This study attempts to investigate the economic merit of investing in modest agricultural water projects and to examine the potential of such investments as a feasible alternative for expanding food production and employment and enhancing rural development in general. This proposition is prompted by the fact that various river basin studies[1] and personal observations seem to indicate the existence of ample opportunities for building a wide network of modest agricultural water projects in Ethiopia. This decision is further strengthened by the consideration that such projects hold out the promise of directly contributing to both food production and employment and are also likely to have widespread benefits for a given amount of financial outlay, with perhaps limited adverse impacts on the environment. As well, since costs are also likely to be relatively low, Ethiopia can afford to experiment with such projects.

The broad purpose of this study, therefore, is to analyze, evaluate and determine whether public water projects

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[1] See: U.S. Department of Interior, Bureau of Reclamation, "Appendix VI: Agriculture and Economics," Land and Water Resources of the Blue Nile Basin of Ethiopia (Washington, D.C.: U.S.D.I., 1964); and Food and Agriculture Organization, Irrigation and Water Planning, Vol. V: Survey of the Awash River Basin, Ethiopia (Rome: F.A.O., 1965).

designed to meet the social objectives of expanding food production and employment and providing a clean rural community water supply can be economically feasible. In particular, the study seeks to establish the potential rate of return to such public investment projects and to indicate the emerging policy implications so that public economic policy makers will have a sound economic basis on which to assign investment priorities and make rational investment decisions.

Because of data restrictions, this study does not systematically analyze the regional and personal income distribution effects of the proposed projects, although passing reference is made to these considerations in the various sections.

Objectives of the Study

The problem considered in and the broad purposes of the present study have been discussed above. The more specific objectives of the study are:

1. To examine the role of water in the development of Ethiopian agriculture.
2. To assess Ethiopia's water resources and evaluate their availability, utilization, and potential contribution to food production and enhancement of rural life.

3. To evaluate the economic and financial feasibility of public investment in agricultural water projects specifically designed to expand food production, increase employment and provide a clean water supply for community use.
4. To examine the feasibility of implementing such resource-based development projects and suggest needed institutional arrangements that can foster, enhance and promote grassroots involvement in the planning and implementation of water projects.
5. To outline, on the basis of the results of the study, possible public policy alternatives with regard to investment in water development.

CHAPTER II

THE ROLE OF WATER RESOURCE DEVELOPMENT IN THE TRANSFORMATION OF ETHIOPIAN AGRICULTURE

It has been stated that food requirements and unemployment constitute the two most urgent economic problems confronting Ethiopia today. Given the present economic structure of Ethiopia, relief from these problems can be logically expected to come primarily from accelerated development of the agricultural sector. Because Ethiopia's economy is dependent on traditional, low productivity agriculture, the rapid development and transformation of this vital sector will not only help solve the more immediate problem of food supply but will also contribute significantly toward the long term development of the economy as a whole.[1]

Fundamentally, agricultural output, or more specifically, foodgrain output, in Ethiopia can be increased either by increasing yields per hectare of land or by increasing the area of land devoted to foodgrain production or both.

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[1] For a succinct discussion of the role and contribution of agriculture to economic development see: J.W. Mellor and B.F. Johnston, "The Role of Agriculture in Economic Development," American Economic Review (September, 1961), pp. 556-593; and W.H. Nichols, "An Agricultural Surplus as a Factor in Economic Development," Journal of Political Economy (February, 1963), pp. 1-29.

Furthermore, the existence of high unemployment of under-employment in the rural labor force suggests that increases in farm output be obtained largely through labor intensive operations. Therefore, to attack these twin problems, Ethiopia's agricultural development strategy needs to be based on a labor intensive model.

Existing agricultural development theory as developed by Shultz, Mellor, and Hayami and Ruttan[1] seems to emphasize the need for introduction of new technology into traditional agriculture in order to achieve self-sustaining growth in agricultural output. Hayami and Ruttan in particular state that agricultural technology takes different "paths" and that the specific "path" adopted by a nation depends on the nature of its resource endowment and the nature of the relationship between factor and product prices. They identify two alternative paths of agricultural technology -- biological-chemical technology and mechanical technology.[2] In their view, biological technology, which is a result of genetic research, has shown a tendency to act as a catalyst to induce the substitution of a relatively

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[1] T.W. Shultz, Transforming Traditional Agriculture (New Haven: Yale University Press, 1964); John W. Mellor, The Economics of Agricultural Development (Ithaca: Cornell University Press, 1966); Yujiro Hayami and Vernon W. Ruttan, Agricultural Development: An International Perspective (Baltimore: The Johns Hopkins Press, 1971).

[2] Ibid., pp. 43-53.

abundant factor for a relatively scarce factor.[1] For instance, they argue that the development of high-yielding seed has induced the substitution of fertilizer for land. They further contend that mechanical technology has been developed as a substitute for scarce labor and as such has remained a characteristic form of technology in the labor scarce countries of the industrialized world.

Hayami and Ruttan explain differences in the international patterns of agricultural technology as being induced by differences in relative resource endowments and the consequent difference between input and output prices. Through an extensive analysis of inter-country data, they show that land scarce countries such as Japan, the Netherlands, Taiwan and Belgium use relatively high rates of fertilizer application per hectare and relatively small amounts of tractor horsepower per male worker, while the reverse seems to be true for such land surplus, labor scarce countries as the United States, Canada, Australia and New Zealand.[2]

The implication of this theory for the development of Ethiopian agriculture is clear. As a labor surplus country, Ethiopia should emphasize the more intensive and widespread use of fertilizer and high-yielding seed varieties. How-

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[1] Ibid., p. 44.

[2] Ibid., pp. 69-81.

ever, applied in isolation, such a policy would inevitably face serious limitations. To begin with, massive amounts of foreign exchange would be required annually in order to purchase sufficient quantities of fertilizer for Ethiopia's crop lands. At current exchange rates and fertilizer prices, Ethiopia would need about one billion Ethiopian dollars annually,[1] more than twice her current total annual foreign exchange earnings, to purchase sufficient fertilizer.

Even if one conveniently ignores the foreign exchange limitation, this strategy by itself would be inadequate for large sections of Ethiopia where moisture scarcity and unreliability impose severe restraints on agricultural production. While this theory may be valid for the relatively moist regions of Ethiopia, particularly the western and central highlands, the vast areas of the lowlands would not benefit from this strategy without a concomitant development of water resources. By and large, the natural resource endowment of Ethiopia is such that moisture is a limiting factor for agricultural production in large sections of the country. In a 1973 survey conducted by the Ministry of Agriculture in four provinces of Ethiopia, over 50 percent of the farmers interviewed identified moisture limitation

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[1] At current exchange rate, U.S. $1.00 = Eth. $2.00 (1975). Current fertilizer price is Eth. $90.00/100 kg. - C.I.F. Assab.

as the main cause of poor yields.[1] In general, the available evidence suggests that the introduction and promotion of fertilizer and high-yielding seed varieties in large parts of Ethiopia without first removing the underlying moisture limitation would, at best, only yield partial results and, at worst, prove to be a costly gamble.

Moisture limitation adversely affects agricultural production in Ethiopia on a broad scale. Besides reducing crop yields, moisture limitation also restricts the range of crops grown in the lowlands of Ethiopia to a few hardy crops such as sorghum and millet. The impact of water shortages during the long dry season is even more disastrous on livestock production. Pastures and grazing lands are often very poor owing to moisture shortages, hence livestock productivity per head is very low. Furthermore, the fact that livestock must be driven over considerable distances in order to satisfy their daily water requirements implies

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[1] Imperial Ethiopian Government, Ministry of Agriculture, Planning and Programming Department, A Photogrammetic Assessment of 1966 E.C. Harvest Conditions in Eritrea, Tigre, Wollo, Northern Shewa and Hararghe (Addis Ababa: I.E.G., 1974), p. 323. (It should, however, be noted that these provinces are drought prone regions and the survey was taken after the 1972 and 1973 drought periods. Nevertheless, the study does show the degree of risk and uncertainty that the Ethiopian farmer faces with regard to rainfall, and this fact will definitely have an effect on whether he decides to use fertilizer and high-yielding crop varieties. Given the degree of risk and uncertainty he faces, his behavior can be predicted to be ultra-conservative when it comes to making what to him is a substantial investment in an uncertain venture.)

that livestock output is sacrificed in the process. In addition, the communal and unprotected nature of the water supply predisposes the herds to communicable diseases and parasites. In view of the high incidence of livestock diseases and parasites in Ethiopia, it is quite plausible that the state of the water supply is, at least partly, responsible for the perpetuation and spread of these diseases.

The most important and devastating impact of water scarcity in Ethiopia, however, is felt by the over 25 million rural population. In rural areas the shortage of water for domestic purposes is so severe that most farm families must travel long distances every day to obtain supplies. Since the amount of water that can be carried home at a given time is sufficient only for cooking and drinking, very little if any water is available for other household uses. The quality of the water is also often so poor that the rural water supply system as a whole is generally regarded as a very serious community health hazard. There is widespread suspicion that waterborne diseases and parasites account for a considerable share of the national health cost and loss in labour productivity.

The role of water in the transformation of Ethiopian agriculture and rural life can hardly be overemphasized. Systematic development of the water resources of a country where water imposes a ceiling on agricultural productivity can be expected to significantly increase agricultural out-

put. The development of water resources can also provide for improved human welfare and a wholesome way of life for the population. In the long run, availability of ample clean water supplies may attract industries and related establishments to rural areas, thereby contributing to the transformation of rural life.

In the remaining portion of this chapter, the role of irrigation in increasing output and employment in agriculture will be examined with the use of formal production models. In addition, the experience of other developing countries with regard to irrigation will be reviewed and the other rural uses of water will be briefly examined.

The Potential Impact of Irrigation Development in Ethiopia

Of all water uses, irrigation represents by far the greatest use of water in agriculture. In regard to irrigation, water resource development can be looked at from two points of view. In one respect, irrigation development can be considered an expansion of the agricultural infrastructure or a form of capital accumulation. To that effect, it is simply a way of substituting capital for land and its tendency is to prevent the inelastic supply of land from becoming a constraint on agricultural production.

On another plane, the introduction of an irrigation system, with its improved water delivery and efficient techni-

ques of water management, represents a new farm technology that can increase yields per hectare. The availability of an adequate, well controlled and properly managed irrigation system will also make the use of improved high-yielding seed varieties more attractive and induce the application of commercial fertilizer and chemical pesticides. In this respect, irrigation technology becomes a land-augmenting technology which enhances the productivity of the land.

The development of irrigation can also be expected to increase labor employment. Since the labor input requirement of irrigation agriculture is relatively high, either the expansion or intensification of cultivation that accompanies new irrigation development can be expected to generate considerable employment opportunities. Additional jobs will be created not only during the construction period, but also during the production, processing, and distribution of the additional output. To more fully examine the potential impact of irrigation development on agricultural production and employment, some simple illustrative production models follow.

Aggregate Agricultural Production Function

The concept of neo-classical production theory is employed here to provide a theoretical explanation of how the introduction of irrigation into a primarily dryland agriculture can increase farm output. Neo-classical produc-

tion theory is so familiar in economics that it hardly needs a detailed explanation.[1] The present exposition is merely intended to illustrate:

1. how moisture limitation can constrain agricultural production;
2. the effect of new viable irrigation schemes on farm output;
3. the effect of the introduction of irrigation schemes on relative factor shares (i.e., the relative distribution of gains from new irrigation projects between land and labor; and
4. the impact of irrigation development on farm labor employment.

Following the standard production function approach, an attempt will be made to formulate a production relation for traditional agriculture under constant technological assumptions and then proceed to investigate the factor-factor

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[1] The available literature on neo-classical production theory is indeed voluminous. The following selected works provide excellent coverage of the basic tenets of neo-classical production theory: S. Carlson, A Study on the Pure Theory of Production (London: P.S. Kings and Co. Ltd., 1939); C.W. Cobb and Paul H. Douglas, "A Theory of Production," American Economic Review, Papers and Proceedings, 18 (1928), pp. 139-165; C.E. Ferguson, The Neo-Classical Theory of Production and Distribution (Cambridge: Cambridge University Press, 1971); Earl O. Heady and John L. Dillon, Agricultural Production Functions (Ames: Iowa State University Press, 1961); John R. Hicks, Value and Capital (Second Edition; Oxford: Clarendon Press, 1946); Gerhard Tintner, "The Pure Theory of Production Under Technological Risk and Uncertainty," Econometrica, 9 (1941), pp. 305-312.

relationships and the nature of product distribution between factors. In the second stage the assumption of constant technology will be relaxed by introducing an irrigation technology. The following possibilities for increasing agricultural production will then be examined:

1. irrigation as a means of expanding cultivated areas;
2. irrigation as a means of intensifying cultivation on existing farm lands.

The final stage of this theoretical formulation attempts to draw some implications of irrigation development for farm labor employment and relative factor shares.

In traditional agriculture, land and labor constitute the two most important factors of production. In order to specify an aggregate production function for traditional agriculture, it is necessary to assume that these two factors are continuously substitutable in the production process. It is also essential to assume that a unique level of output corresponds to each combination of these inputs. With these assumptions, an agricultural production function can be specified as follows:

$$Q = F(N,L) \tag{2.1}$$

$$F_L \geq 0$$

$$F_N \geq 0, \quad F_{LL} < 0, \quad F_{NN} < 0$$

where Q = Aggregate agricultural output.

N = Agricultural land.

L = Agricultural labor force.

F_N and F_L are marginal products of land and labor, respectively. Since along a given isoquant Q remains constant:

$$F_N dN + F_L dL = 0 \qquad (2.2)$$

At equilibrium, $-\frac{dL}{dN} = \frac{F_N}{F_L}$ = marginal rate of technical substitution (MRTS) between the two factors. It is assumed that the MRTS decreases as labor is substituted for land, i.e., the isoquant is convex to the origin. Assume further that the production function is of the constant returns to scale type. Hence:

$$F(\lambda N, \lambda L) = \lambda F(N,L) \quad \text{for all } \lambda > 0 \qquad (2.3)$$

Then by Euler's theorem:

$$Q = F_N N + F_L L \quad \text{for all N and L} \qquad (2.4)$$

Equation (2.4) states that if each factor is paid according to its marginal productivity, the total product will be exhausted.

In traditional agriculture, the supply of arable land (N) is fixed and only labor (L) is the variable factor. A production function depicting the production relationship of traditional agriculture may be represented as in Figure 2.1.

Figure 2.1 illustrates a typical neo-classical production function, satisfying all the standard assumptions pertaining thereto. In this diagram, the labor input is measured along the horizontal axis, the land input along the vertical axis. The isoquants Q_1, Q_2, and Q_3 respectively show successively increasing levels of output that can be produced by combining land and labor in various proportions. In view of the fact that readily cultivable land is more of a limiting factor than labor in traditional agriculture, the available arable land is arbitrarily fixed at $\bar{N}$ and the labor supply available to agriculture is set at $\bar{L}$.

Within the environment of unchanging traditional technology, then, the fixed supply of arable land imposes a ceiling on total agricultural output. As noted in the diagram, quantity produced increases from Q_1 to Q_2 as quantity of labor input employed increases from L_A to L_B, land remaining constant at $\bar{N}$. However, Q_3 represents the maximum quantity of agricultural output and L_E the maximum level of employment that can be achieved before the marginal producti-

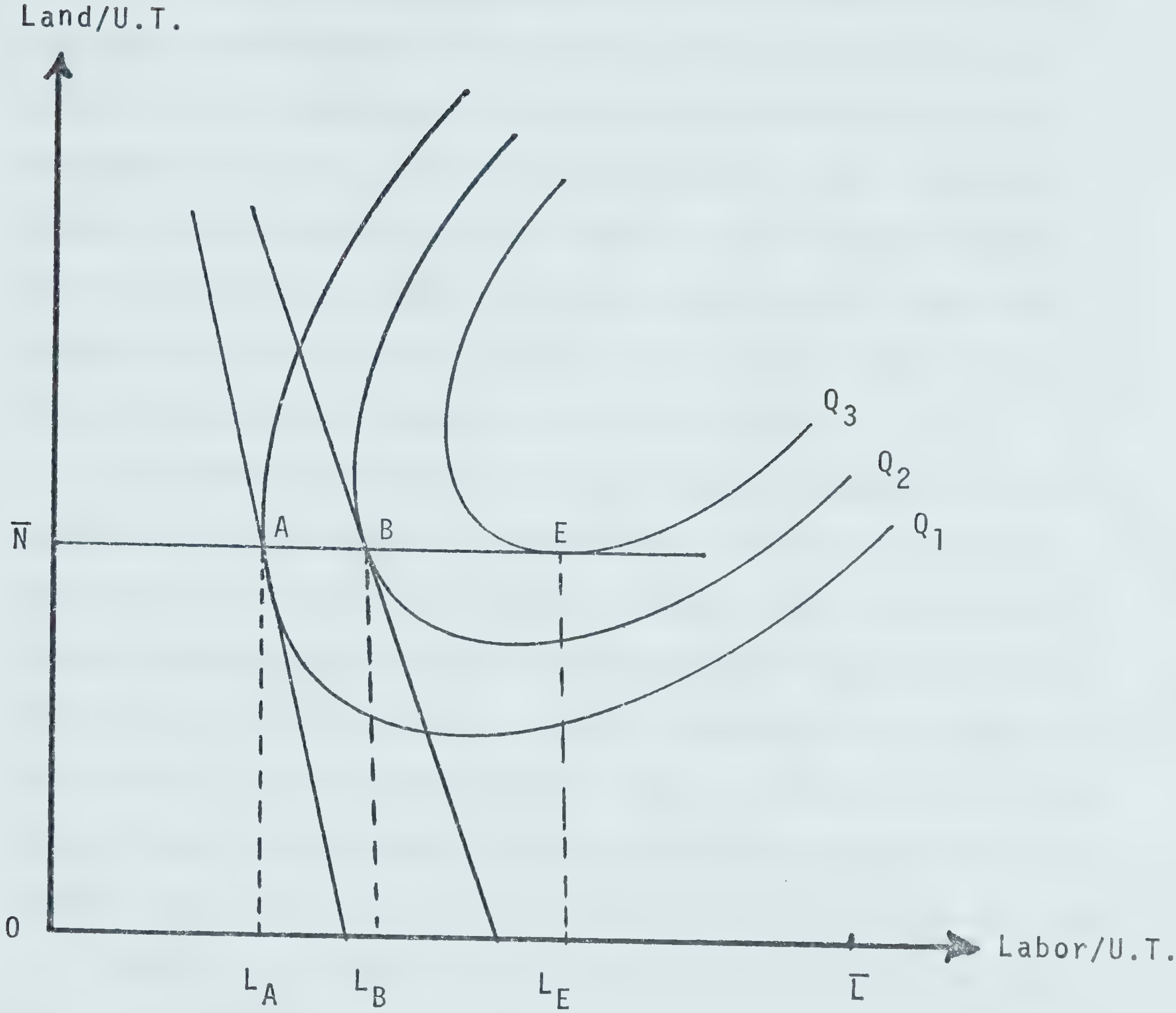

FIGURE 2.1

AGRICULTURAL OUTPUT AND EMPLOYMENT UNDER CONDITIONS OF FIXED ARABLE LAND AND TRADITIONAL TECHNOLOGY

vity of labor falls below zero. As the employment level approaches L_E, land remaining constant at $\overline{N}$, the marginal productivity of labor approaches zero. At point E, the marginal productivity of labor is zero and agricultural output is at a maximum. Therefore, attempting to expand employment beyond L_E, without first easing the land constraint, will only result in reduced total output because each unit of labor added after L_E contributes a negative quantity to total output. Hence the surplus labor $\overline{L} - L_E$ cannot be gainfully employed in agriculture.

In order to increase the quantity of aggregate agricultural output beyond Q_3, either the efficiency of both labor and land must be increased through the introduction of new technology, in which case each existing combination of land and labor produces a larger quantity of output, or more arable land must be brought under cultivation. In the latter case, total output can be increased because there is surplus labor that can be combined with the additional land.

While the concept of how the expansion of cultivated area will lead to increases in output and employment, even under conditions of fixed technology, is fairly self-evident, the idea of how an introduction of new technology can remove the ceiling on production and employment imposed by the scarcity of readily cultivable land may not be so easily understood. Therefore, with some modification, the preceding model can be employed to examine the impact of introducing a new land-augmenting farm technology on production,

employment, and the distribution of potential gains among the factors of production.

Technical progress in traditional agriculture can be assumed to take one of three forms, depending on the nature of resource endowment and the attendant factor price relationships.[1] It can be land augmenting, neutral or labor augmenting. Following Hicks's classification of technical progress,[2] a given farm technology can be said to be land augmenting, neutral, or labor augmenting if at the originally prevailing land/labor ratio, the marginal rate of technical substitution of land for labor diminishes, remains unchanged, or increases after the introduction of the new technology. To properly illustrate these concepts and their implications for agricultural production, farm labor employment and distribution, it is convenient to assume a more specific form of the model already introduced in (2.1).

Assume a Cobb-Douglas type agricultural production function:

$$Q = N^{\alpha}L^{\beta}, \quad \alpha + \beta = 1, \quad \alpha > 0, \quad \beta > 0 \qquad (2.5)$$

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[1] For a fuller discussion of technological progress and the neo-classical theory of production see: C.E. Ferguson, The Neo-Classical Theory of Production and Distribution, pp. 215-234.

[2] J.R. Hicks, The Theory of Wages (Second Edition; London: Macmillan, 1963), p. 121. It should be noted that Professor Hicks explains technical progress in terms of capital and labor factors rather than land and labor as used here.

where Q, L, and N are as defined in (2.1). If a land-augmenting technology, progressing at a constant positive rate of λ, is introduced, the production function will take the form:

$$Q^*_{(t)} = (e^{\lambda t}N)^{\alpha}L^{\beta}, \quad \lambda > 0 \tag{2.6}$$

$$Q^*_{(t)} = e^{\lambda\alpha t}N^{\alpha}L^{\beta} \tag{2.7}$$

$$\frac{\partial Q^*_{(t)}}{\partial N} = \alpha e^{\lambda\alpha t}N^{\alpha-1}L^{\beta} \tag{2.8}$$

$$\frac{\partial Q^*_{(t)}}{\partial L} = \beta e^{\lambda\alpha t}N^{\alpha}L^{\beta-1} \tag{2.9}$$

Since the production function is linear and homogeneous and $e^{\lambda\alpha t} > 1$, $Q^*_{(t)}$ in (2.7) is larger than Q in (2.5), which implies that a land-augmenting technology progressing at the constant positive rate of λ will increase agricultural output at the rate of $e^{\lambda\alpha t}$.

Since a new irrigation system is a land-augmenting technology, its effect on production is therefore positive and direct. Assessing its impact on employment, however, requires further analysis.

Suppose that there is significant unemployment in the

economy and that by a public policy action, irrigated land expands at the constant proportional rate of n so that $\frac{1}{N}\frac{dN}{dt} = n$. Through derivation of (2.8), the following logarithmic form is obtained:

$$\ln Q^*_{(t)} = \lambda\alpha t + \alpha \ln N + \beta \ln L \tag{2.10}$$

$$\frac{1}{Q^*_{(t)}} \frac{dQ^*_{(t)}}{dt} = \lambda\alpha + \alpha n + \beta \frac{1}{L}\frac{dL}{dt} \tag{2.11}$$

$$\frac{1}{Q^*_{(t)}} \frac{dQ^*_{(t)}}{dt} = (\lambda + n)\alpha + \beta \frac{1}{L}\frac{dL}{dt} \tag{2.12}$$

According to (2.8), given the rate of expansion of irrigated land, there is a linear relation between output and employment. If we assume for ease of computation that both output and employment increase by a constant proportional rate (k), i.e.,

$$\frac{1}{Q^*_{(t)}} \frac{dQ^*_{(t)}}{dt} = \frac{1}{L}\frac{dL}{dt} = k,$$

equation (2.12) can be restated as:

$$k = (\lambda + n)\alpha + \beta \tag{2.13}$$

$$k = \frac{(\lambda + n)\alpha}{1 - \beta}\text{, since } \alpha + \beta = 1 \text{ by assumption in (2.5).}$$

$$k = (\lambda + n).$$

Therefore, agricultural output (Q) and labor employment (L) will grow by (λ + n) if irrigation technology advances at the rate of λ and irrigated land expands at the rate of n.

The question of how the increased output is shared by the owners of land and labor is fundamental to economic policy. Under pure competition, relative factor shares depend on the nature of technical progress itself and on the elasticity of substitution between the two factors.[1]

The elasticity of substitution between land and labor given by the formula

$$\sigma = \frac{\partial(\frac{N}{L})}{(\frac{N}{L})} \div \frac{\partial(\frac{f_L}{f_N})}{(\frac{f_L}{f_N})}$$

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[1] J.R. Hicks, The Theory of Wages, pp. 112-135. Also see: Kenneth Boulding, "The Fruits of Progress and the Dynamics of Distribution," American Economic Review, Papers and Proceedings, 63 (1953), pp. 472-483; Murray Brown and John S. Decani, "Technological Change and the Distribution of Income," International Economic Review, 4 (1963), pp. 289-309; C.E. Ferguson, "Neo-Classical Theory of Technological Progress and Relative Factor Shares," Southern Economic Journal, 34 (1968), pp. 490-504. Ferguson also develops the concept in C.E. Ferguson, Micro-Economic Theory (Homewood, Illinois: Richard D. Irwin, Inc., 1969), p. 388.

is a coefficient that indicates the percentage change in the land/labor ratio associated with the percentage change in the ratio of the marginal rate of technical substitution between the two inputs.[1] Since at purely competitive equilibrium the marginal rate of technical substitution is equal to the input price ratio, changes in the equilibrium value of the marginal rate of technical substitution can arise from changes in the price level of any of the inputs. Assuming w, r and p to represent the prices of labor, land and output, respectively, the elasticity of substitution can be restated as:

$$\sigma = \frac{\partial(\frac{N}{L})}{(\frac{N}{L})} \div \frac{\partial(\frac{w}{r})}{(\frac{w}{r})}$$

and the relative factor shares can be expressed as $\frac{wL}{pQ}$ for labor and $\frac{rN}{pQ}$ for land. Thus the ratio of relative shares = $\frac{wL}{rN}$.

If in this model land rent increases due to an exogenous factor, such as population growth, the labor wage remaining constant, there will be a tendency to substitute labor for land through such activities as more intensive cultivation, control of erosion, the filling of gullies and other forms of land reclamation. This tendency to substitute

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[1] C.E. Ferguson, <u>Micro-Economic Theory</u>, p. 384.

labor for land will cause the land/labor ratio to decline, and thereby affect the relative share of the output going to each input. Precisely how the relative shares are affected is determined by the magnitude of elasticity of substitution. If the elasticity of substitution is greater than unity, a given rise in land rent will result in a higher share of the output going to labor. In general, the relative share of labor will increase, remain constant or decrease as the elasticity of substitution is greater than, equal to, or less than unity.[1]

The nature of technical progress will also affect the relative share of factors. If technical progress is neutral by definition this means that the land/labor ratio and the factor price ratio remain constant and, hence, relative factor shares also remain constant. However, if technology is either land augmenting or labor augmenting, relative factor shares are affected so as to favor the augmented factor. Hence, the land owners' share increases relative to the share of labor if technology is land augmenting and vice versa.[2]

Having outlined in general terms the effect of a new farm technology on production and income shares, the subsequent discussion will attempt to focus on irrigation as

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[1] C.E. Ferguson, The Neo-Classical Theory of Production and Distribution, pp. 243-245.

[2] Ibid., pp. 235-252.

a land-augmenting technology and will conceptualize, with the use of a simple diagram, the likely impact of introducing this technology on farm production and employment.

In Figure 2.2 the land factor is measured along the vertical axis and labor is measured along the horizontal axis. $\overline{N}$, on the vertical axis, represents the maximum available physical supply of land, and N indicates the maximum amount of land naturally suitable for ready cultivation under the existing traditional technology. More specifically, N signifies the area of land that is currently cultivated or is capable of producing crops without irrigation, while $\overline{N}$ - N denotes the presently non-cultivable arid and semi-arid regions. Scarcity of moisture is assumed to be the primary limitation to the expansion of crop production in the semi-arid and arid areas. $\overline{L}$, on the horizontal axis, represents the maximum available supply of active labor force in agriculture at a given time. The isoquants are assumed to satisfy all the standard assumptions of neo-classical production theory.

In the model, the isoquant Q represents the maximum amount of aggregate agricultural output that can be produced under the existing levels of resource availability and technology. Output cannot increase beyond this level under the existing technology because the total supply of readily cultivable land, N, has been used up and any further addition of labor beyond L_E will only diminish total output. L_E, therefore, represents the maximum level of employment

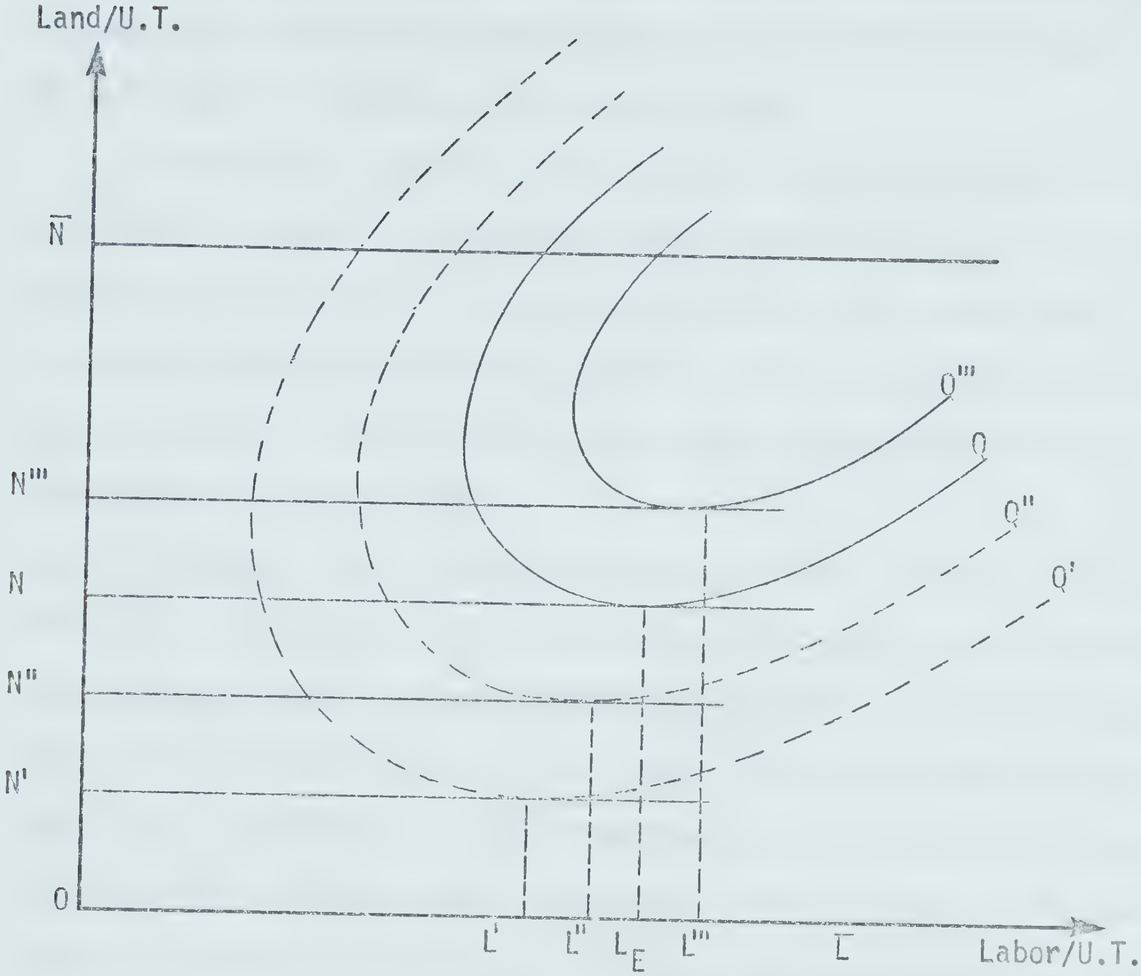

FIGURE 2.2

AGRICULTURAL OUTPUT AND EMPLOYMENT
UNDER CONDITIONS OF TECHNICAL PROGRESS

and there exists a labor surplus of the magnitude $L_T - L_E$. Under these circumstances, to increase output and employment in agriculture, it is essential to remove the ceiling imposed on output and employment in agriculture by the limitation of readily cultivable land.

Naturally, agricultural output and employment can be increased either by intensifying operations on N units of good quality land or by extending cultivation into the currently uncultivated $\overline{N}$ - N units of arid and semi-arid land or both. To do either or both, of course, requires investment in new inputs.

Suppose that a new technology in the form of supplementary irrigation (including all techniques of water control and delivery and improved farm management) was introduced into the existing cultivated areas. The introduction of this new technology can be expected to increase yield per hectare as well as total output per year. This increase in output per unit of time may be represented in Figure 2.2 by an inward shift of the isoquant Q to one similar to Q'. Consequently, N' and L' becomes the new land/labor combination needed to produce the level of output that formerly required the maximum readily cultivable supply of land, N, and L_E units of labor under the previous technology. Under the new situation, output and employment can continue to expand beyond Q' and L', respectively, until the N units of land are entirely covered by the new technology.

While the foregoing is a case of intensive cultivation

as a result of water availability, a similar argument can be used to explain the case of expanding cultivation to new lands through the provision of new irrigation facilities. Cultivation can be extended into the largely semi-arid area indicated by $\overline{N} - N$ through the provision of new irrigation schemes. If cultivable land is increased from N to N''' through an initial investment in irrigation and attendant technology, total output can be increased from Q to Q''' and employment can expand from L_E to L'''. Aggregate agricultural output can then continue to expand until the new technology covers the potentially cultivable physical supply of land. Alternatively, an integrated plan of intensification and area expansion can be pursued as a long term agricultural development strategy.

On purely conceptual grounds, therefore, it is quite clear that investment in water development can make significant contributions to the development of Ethiopian agriculture. In particular, the availability of adequate amounts of irrigation water at the right time and place can lead to increased agricultural production through increases in yield per unit of land or through multiple corpping and expansion of cultivated area. In regions with low and uncertain rainfall, the availability of irrigation water can make the adoption of high-yielding seeds, fertilizer and chemicals economically attractive and thereby set in motion the process of agricultural transformation.

Labor employment can be expected to expand not only

during construction of the project, but also on an ongoing basis as cultivated area is expanding, as fields are more intensively cultivated, and as the additional output is harvested, assembled, processed, and marketed.

Irrigation Experience of Other Developing Countries

While the theoretical formulation is useful in providing a conceptual framework, the most important task is to investigate the extent to which these theoretical expectations have been borne out in practice. There is no doubt that historically irrigation has played a very strategic role in man's attempt to produce food and fiber. It is an historical fact that some of the world's greatest civilizations were based upon irrigation and these civilizations later declined as the irrigation system failed because of salinity build-up and other related problems.[1]

During the last hundred years, irrigation technology and the amount of irrigated area in the world have been vastly increased. World irrigated area is said to have risen from a mere 8 million hectares in 1880[2] to about 200

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[1] President's Science Advisory Committee, The World Food Problem, Volume II, Report of the Panel on the World Food Supply (Washington, D.C.: The White House, May, 1967), p. 440.

[2] Ibid., p. 441.

million hectares in 1974.[1] Nevertheless, irrigated acreage still accounts for a relatively small share of total cultivated area on a world basis, but it is of prime importance in certain regions and specific countries.

With the exception of Japan, irrigated area constitutes a far larger share of harvested area in the developing countries than in the developed countries (Table 2.1). Certain developing countries (see Table 2.2) depend almost entirely on irrigation for crop production.

Even more revealing in this regard are the figures in Table 2.3. Over the period 1961-63, the countries of the Near East and N.W. Africa received 68 percent of the value of crop production from irrigated lands. The comparable figures for Asia and the Far East, Latin America, and Africa south of the Sahara were 40 percent, 17 percent and 3 percent, respectively.[2]

These figures merely reflect the underlying climatic conditions in these countries which make the use of irrigation imperative. Since most of the developing countries lie within the tropics and subtropics, inadequacy of annual rainfall or unfavorable seasonal distribution and a high rate of evapotranspiration make supplemental irrigation of

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[1] F.A.O., Production Yearbook, 1974 (Rome: F.A.O., 1975), pp. 3-7.

[2] F.A.O., Provisional Indicative World Plan for Agricultural Development, Volume I (Rome: F.A.O., 1970), p. 46.

TABLE 2.1

MAJOR IRRIGATING COUNTRIES, ACCORDING TO AMOUNT OF IRRIGATED AREA[1] (1,000 Hectares)

Country	Year[2]	Cultivated Area[3]	Irrigated Area	Percentage Irrigated
China (PRC)	1967 (1960)	110,300	75,980	68.9
India	1968	164,610	27,520	16.7
United States	1969	192,318	15,832	8.2
Pakistan	1969	19,235	12,505	65.0
U.S.S.R.	1970	232,809	11,100	4.8
Indonesia	1969	18,000	6,800	37.8
Iran	1971	16,727	5,251	31.4
Mexico	1960 (1964)	23,817	4,200	17.6
Iraq	1970 (1963)	10,163	3,675	36.2
Egypt	1971	2,852	2,836	100.0
Japan	1970	5,510	2,444	51.5
Italy	1971 (1960)	12,409	2,435	19.7
Spain	1970	20,626	1,830	11.8
Thailand	1965 (1969)	11,415	1,555	16.0
Argentina	1968 (1959)	26,028	1,549	6.0
Turkey	1970 (1967)	27,378	1,476	5.7
Australia	1969	44,610	1,091	3.3
Chile	1965 (1964)	4,632	1,116	23.6
Peru	1971	2,979	1,021	37.5
Bulgaria	1971	4,516	--	22.6
Total[4]		1,457,000	203,600	14.0

[1] Includes individual countries having irrigated areas exceeding one million hectares.

[2] Year refers to year for which data on cultivated area apply; year in parentheses refers to year for irrigation area data when different from year for cultivated area data.

[3] Cultivated area is arable land plus land under permanent crops.

[4] Total and numerical values should be regarded as approximate because of incomparability of data between countries and different years of data collection.

SOURCE: U.S.D.A., Economic Research Service, The World Food Situation and Prospects to 1985 (Washington, D.C.: U.S.D.A., 1974), p. 70.

crucial importance to agricultural production. The insurance that supplemental irrigation provides against disastrous droughts that occur with amazing regularity in these regions is also of vital importance to the welfare and survival of the people who live in this part of the world.

It might very well be true that future breakthroughs in crop research might develop varieties suitable for arid and semi-arid areas. Work in this direction has already been initiated in some international research institutions.[1] It will undoubtedly be several years before a substantial breakthrough can be realized in the development of high-yielding seed varieties for the arid and semi-arid areas of the world.

In the immediate future, therefore, the developing countries have to rely on the use of existing crop varieties for producing the urgently needed food. Unfortunately, the high-yielding wheat and rice varieties that sparked the so-called "green revolution" in Asia require well controlled and properly managed supplies of water as well as adequate fertilization in order to produce optimum yield. Hence, they may not provide a viable alternative in countries where irrigation is poorly developed. Being acutely aware of this

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[1] The International Institute of Tropical Agriculture in Nigeria and the Institute of International Crop Research for the Arid and Semi-Arid Tropics in India are two main institutions doing research relevant to the semi-arid areas of the tropics.

TABLE 2.2

TWENTY-FIVE MAJOR IRRIGATING COUNTRIES, ACCORDING TO PERCENTAGE OF AREA IRRIGATED[1] (1,000 Hectares)

Country	Year	Cultivated Area	Irrigated Area	Percentage Irrigated
Egypt	1970	2,852	2,852	100.0
China	1967 (1960)	110,300	75,980	68.9
Pakistan	1969	19,235	12,505	65.0
Taiwan	1969	867	500	57.7
Japan	1970	5,510	2,836	51.5
Israel	1971	417	173	41.5
Albania	1967	556	227	40.8
Indonesia	1969	18,000	6,800	37.8
Peru	1971	2,979	1,116	37.5
Iraq	1970 (1963)	10,163	3,675	36.2
Korea, Rep. of	1969 (1968)	2,311	759	32.8
Iran	1971	16,727	5,251	31.4
Cyprus	1968 (1967)	432	102	23.6
Chile	1965 (1964)	4,632	1,091	23.6
Ceylon	1970	1,979	465	23.5
Bulgaria	1971	4,516	1,021	22.5
Madagascar	1966	2,900	620	21.4
Italy	1971 (1960)	12,409	2,444	19.4
Greece	1968 (1969)	3,631	711	19.6
Viet Nam, Rep. of	1971	3,065	580	18.9
Mexico	1960 (1964)	23,817	4,200	17.6
Somalia	1960	957	165	17.2
India	1968	164,610	27,520	16.7
Saudia Arabia	1967	809	131	16.2
Thailand	1965 (1969)	11,415	1,830	16.0

[1] Includes only countries with more than 100,000 hectares of irrigated area. Year refers to year for which data on cultivated area apply; year in parentheses refers to year for irrigation area data when different from year for cultivated area data. Cultivated area is arable land plus land under permanent crops.

SOURCE: U.S.D.A., Economic Research Service, The World Food Situation and Prospects to 1985 (Washington, D.C.: U.S.D.A., 1974), p. 71.

problem, the F.A.O. Indicative World Plan states:

> As modern cash inputs are successfully removing or reducing the effects of many limiting factors, even in areas of moderately adequate precipitation, there is an increasing need to consider supplementary irrigation to avoid moisture availability becoming the ceiling on yields.[1]

In general, there seems to be a high correlation between irrigation water availability and the area planted to the new high-yielding varieties.[2] The F.A.O. Indicative World Plan, for instance, estimated that out of 140 developing countries, only about 25 were using the high-yielding crop varieties on a large scale in 1968 and these were mostly countries where irrigation was relatively well developed.[3]

In countries that have achieved agricultural breakthroughs in recent years, such as Mexico, Pakistan and Taiwan, irrigation seems to have played a very important role (Table 2.1). On the other hand, the adoption of improved varieties has been very slow in Africa south of the Sahara, where water is scarce and irrigation facilities are extremely limited (Table 2.3). Since improved seeds and fertilizers can be imported from abroad, there is no doubt that water is the most limiting factor hampering the

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[1] F.A.O., Provisional Indicative World Plan for Agricultural Development, Volume I, p. 47.

[2] Ibid., p. 83.

[3] Ibid., p. 98.

TABLE 2.3

IMPORTANCE OF IRRIGATION ACCORDING TO REGIONS (1961-63)

Region	Irrigated Area (Mill. Ha.)	Irrigated Area as Percentage of		Value of Crop Production from Irrigated Land Percentage of Total
		Arable Area	Harvested Area	
Africa South of the Sahara	1	0.7	1.7	3
Asia and Far East	44	20.9	23.5	40
Latin America	11	8.1	11.5	17
Near East and N.W. Africa	17	23.9	32.9	68
Total or Average	73	12.9	18.6	34

SOURCE: F.A.O., Provisional Indicative World Plan for Agricultural Development, Volume I (Rome: F.A.O., 1970), p. 46.

large-scale adoption of this new technology in sub-Saharan Africa. In fact, as Time Magazine[1] puts it: "From Central America to Asia, the main limit on the wider use of miracle seeds is the lack of water. The F.A.O. estimates that global demand for water will expand 240 percent by the century's end...."

Undoubtedly, the future expansion of high-yielding seed use will be governed by water availability. The F.A.O. Indicative World Plan envisages a large portion of the additional area planted with the new seeds to be irrigated. The 1985 projection of the F.A.O. plan for the adoption of new varieties clearly points to the increasing importance of irrigation as a source of agricultural productivity growth in the less developed countries.

While empirical evidence showing the positive effects of irrigation and the new high-yielding seed technology on production has been mounting, the record has not been as impressive for employment generation and income distribution. By and large, the employment generating capacity of the "green revolution" has not been as originally expected. The available evidence seems to indicate that the "green revolu- in South East Asia has intensified the rural unemployment problem. The process seems to have accelerated the rate of tenant eviction because landlords found it increasingly

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[1] "Special Report on the World Food Crisis," Time, 11 November 1974, p. 82.

profitable to substitute modern farm machinery for labor.[1]

The distribution of gains from the new agricultural technology has also been skewed in favor of the landlords. This has further sharpened the conflict between the small landowning class and the large mass of landless peasants.[2] Of course, it should be pointed out that these problems did not originate with the green revolution. Their origin lies in the anachronistic system of property ownership that characterizes a great majority of the developing countries. Superimposition of the new technology into the tradition bound, largely feudal system of property relations has simply exascerbated the inherent defects and inequities of the system. It is thus largely the failure of the social and institutional system to adapt itself to new situations which is responsible for some of the major shortcomings of the new agricultural technology in many developing countries. A realistic policy of agricultural development should, therefore, treat both technology and institutions as endogenous

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[1] For a detailed discussion of the unemployment and income distribution problem of the green revolution see: Walter P. Falcon, "The Green Revolution: Second Generation Problem," American Journal of Agricultural Economics, Vol. 52, No. 5 (December, 1970), p. 698; Laurence Hemes, Rural Development: World Frontiers (Ames: The Iowa State University Press, 1974); Thomas T. Poleman and D.K. Freebairn, Editors, Food, Population and Employment: The Impact of the Green Revolution (New York: Praeger Publishers, 1973).

[2] Keith Griffin, The Political Economy of Agrarian Change: An Essay on the Green Revolution (London: Macmillan, 1974).

variables

Non-Irrigation Uses of Water

While the benefits of irrigation, particularly in an arid climate, are clear and visible, the benefits of water development programs are by no means restricted to irrigation only. As subsequent discussion will show, there are some not so visible, but nevertheless vital, services that can result from developed water systems.

Household Water Supply

A well developed community water resource can serve as a sanitary source of domestic water supply. Aside from the immense welfare implication of an ample supply of fresh water for domestic use, a clean and safe household water supply can have substantial and measurable economic benefits. Reduction in public health costs and savings in man-hours lost due to illness caused by water borne diseases are only a few of the readily recognizable economic benefits of community water development. A national program of water development can therefore greatly contribute to the enhancement of a healthy, energetic and more productive population.

Livestock Water Supply

The livestock industry is a very important component

of Ethiopia's agricultural economy. The promotion of this industry should be an integral part of the agricultural development program. But the development of a vigorous livestock industry depends, among other things, on the availability of adequate and clean stock water supplies. A reliable source of water is required not only for direct stock consumption but also for the development of pastures and rangelands, which are vital for increasing the quality and quantity of livestock output. An additional economic benefit may also be realized through the reduction of veterinary costs over and above those that may accrue from improved livestock production if adequate and clean water supplies are provided.

Wildlife Conservation and Development

The availability of a well developed water system would also encourage the growth of fish and wildlife. If properly managed, these resources could be a good supplemental source of food, particularly good quality protein. Water-based sports and recreation could also be expanded, thereby enhancing the well-being of the community as a whole.

Rural Industrial Development

The development and expansion of any sort of modern farm processing industry will require the ready availability of large quantities of water. It is characteristic of

modern industry to use large volumes of water either directly in the manufacturing process or for cooling, cleaning, and waste disposal purposes. This is particularly true for agricultural processing industries. In addition, modern life-styles require increasing quantities of water per capita, and as industries and towns expand, the demand for municipal uses of water can be expected to increase dramatically. The early development of water resources, therefore, can lay the foundation for future industrial and township development in Ethiopia.

Timber Development and Soil Conservation

The introduction of good watershed management and water conservation associated with water development can be of immense value in flood control, soil conservation and timber development. These activities can also have widespread economic benefit in a mountainous country like Ethiopia where large areas of productive farm lands are being reduced every year by erosion resulting from rapid and uncontrolled run-off.

These uses, of course, do not exhaust the entire range of benefits that can result from water resource development. For instance, medium- and large-scale water projects could be developed for hydro-electric power generation. However, it is beyond the scope of this study to go into these types of projects.

In the final analysis, two important conclusions seem

to emerge from the foregoing discussion: (1) water development is vital for the stabilization of food supply and transformation of Ethiopian agriculture, and (2) the development of integrated agricultural water projects can directly and effectively contribute to the progress and well-being of the rural population of Ethiopia.

CHAPTER III

ETHIOPIA'S WATER RESOURCES: A DESCRIPTIVE APPRAISAL

In view of the potentially important role water can play in the development and transformation of Ethiopian agriculture, the question that logically follows is: Does Ethiopia possess sufficient quantities of water resources that can be developed for agricultural and other purposes? In other words, is Ethiopia adequately endowed with the requisite quantity and quality of water supplies that can be developed to meet the demands of the various sectors of the economy? It is the purpose of this chapter to attempt to provide some answers to these and related questions.

Although knowledge about Ethiopia's water resource endowment is far from being complete, considerable information has been gathered over the last fifteen years. Detailed studies of two river basins -- the Abay and the Awash Basins -- have been completed and a study of the Wabi Shebelle Basin is in the final stages of completion. Minor local and ground water surveys have been conducted in different parts of the country.[1] There are further

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[1] For a broader discussion on Ethiopia's water resources see: Imperial Ethiopian Government, Ministry of Planning and Development, Regional Aspects of National Planning in Ethiopia, Part I, p. 26, and Part II, Appendices B and D.

encouraging signs that a number of government agencies[1] are intensifying efforts to compile and make available water resource data on a continuing basis. These endeavors are contributing greatly to the growing knowledge of the state of the nation's water resources.

The important available information have been brought together in this chapter with the aim of assessing the prospects for irrigation development. Primary emphasis is placed on establishing the general magnitudes of the available sources of water supply and the demands put on them rather than on providing firm quantitiative estimates. The chapter begins with a consideration of the supply side of Ethiopia's water resource system, the components of which are precipitation and various types of surface and ground water sources (Figure 3.1). It then discusses the various classes of demand for water in Ethiopia, including household demand, agricultural demand, industrial demand and demand for flow uses of water. The chapter concludes with a brief remark on quality aspects of Ethiopia's water systems.

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[1] Among the main agencies concerned with water and water-related problems in Ethiopia are The National Water Resources Commission, The Awash Valley Authority, The National Climatological Service, The Marine Department, The Addis Ababa Water and Sanitation Authority, The Ethiopian Electric Lights and Power Authority, The Institute of Agricultural Research, The Ministry of Agriculture, and The Municipalities Department of the Ministry of Interior.

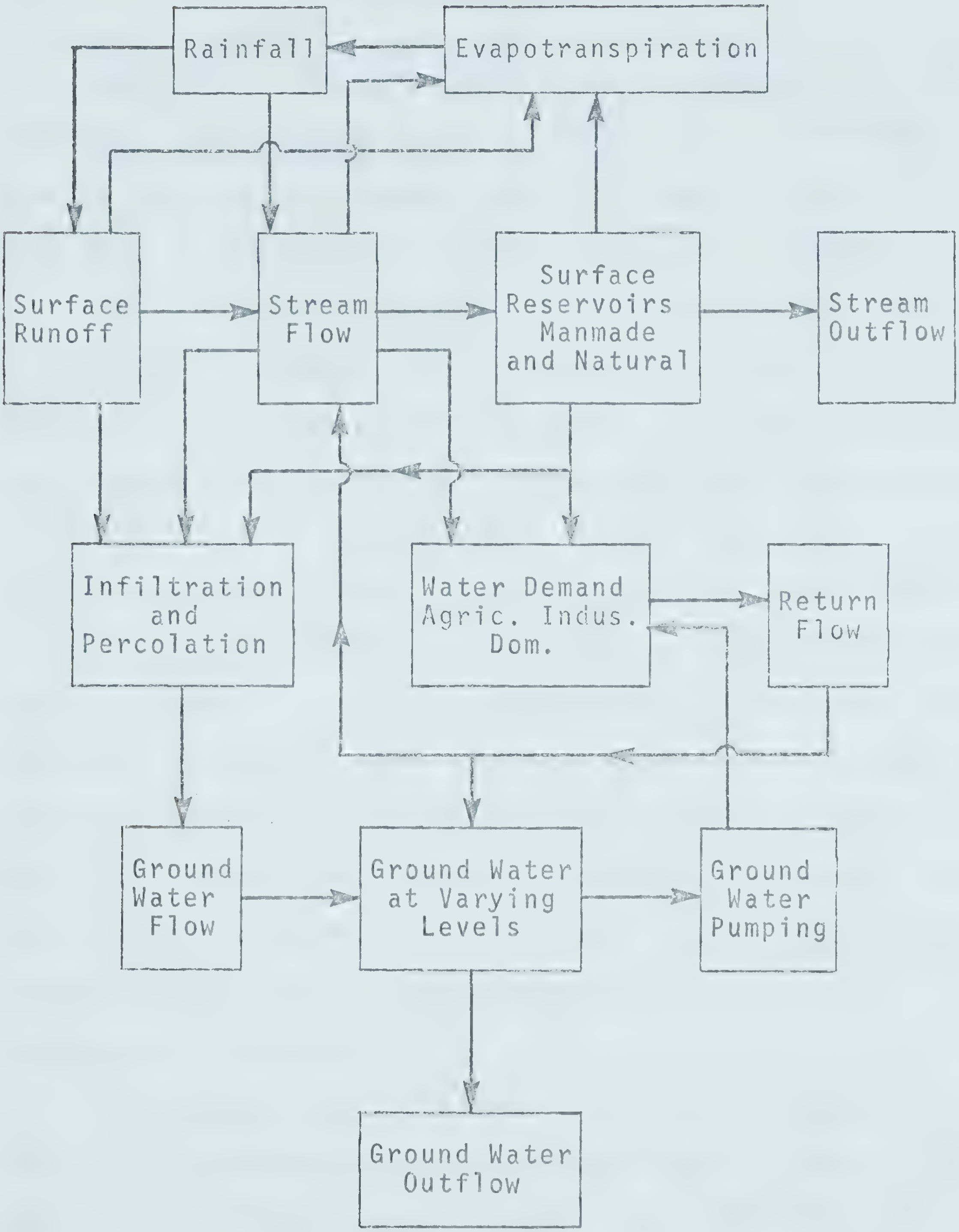

FIGURE 3.1

A SCHEMATIC DIAGRAM OF ETHIOPIA'S WATER RESOURCE SYSTEM

Precipitation

Rainfall is the principal form of precipitation and, therefore, the primary source of fresh water in Ethiopia. Snow is totally nonexistent and other forms of precipitation such as dew and hail occur in negligible amounts.

The full significance of rainfall to the welfare of the people of Ethiopia can be realized only when one considers the fact that almost the entire agricultural production system rests on dryland farming and that agriculture is the backbone of the Ethiopian economy. An equally significant point is that surface and ground water sources in Ethiopia obtain their replenishment strictly from the annual rainfall. It is also interesting to note that the available sources of water strictly depend on the amount of rainfall that occurs within Ethiopia's borders as there are no rivers flowing into Ethiopia from other countries. On the contrary, most of Ethiopia's major rivers flow across national boundaries to become the mainstay of life in neighbouring countries.[1]

As elsewhere on the globe, the rainfall regime in Ethiopia is governed by the hydrologic cycle. Solar radiation and wind movement, two factors over which man has absolutely no control, provide the energy which keeps the hydrologic cycle in perpetual motion. Although very effi-

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[1] Mesfin Wolde Mariam, An Atlas of Ethiopia, p. 14.

cient as a gigantic desalination and global fresh water conveyance system, the hydrologic cycle leaves a lot to be desired as a system of global fresh water distribution. The conveyance system is, by and large, very capricious and the allocation process is neither reliable nor entirely fair and equitable on a global basis. Consequently, fluctuations from the established patterns of rainfall occasioned by a change in the direction of the moisture carrying winds or the amount of moisture they carry are quite frequent. Such fluctuations of course, can, and do, from time to time, produce profound impact on the economic activity of a given locality or region.

Given the predominance of such a stochastic factor in Ethiopia's agricultural production system, plans aimed at achieving accelerated agricultural growth run a very high risk of being frustrated unless real efforts are made to compensate for these inadequacies. As the most crucial variable in Ethiopia's water resource equation, therefore, rainfall needs to be looked at very closely. In particular, certain characteristic features of rainfall that have profound implication for agricultural production need to be identified and carefully scrutinized. The most important of these features are: the quantity of annual rainfall, its temporal and spatial distribution and its intensity. These vital features are briefly discussed below.

Average Annual Rainfall

The average annual rainfall in Ethiopia varies from less than 100 mm in the extreme northern and southeastern portions of the country to 2,500 mm in the southwestern highlands (Figure 3.2). Over the country as a whole, the amount of annual rainfall seems to be positively correlated with altitude and negatively correlated with latitude and longitude.[1]

It is difficult to estimate precisely the total volume of rain that falls over Ethiopia in any given year. However, an effort was made to obtain a rough quantitative estimate of the total volume of rainfall in an average year by using the following formula:

$$R = A \times H$$

where R = Total volume of rainfall for an average year measured in hecta-metres.

A = Average annual rainfall for the nation as a whole measured in meters.

H = Total land area of the country in hectares.

The crucial variable in estimating this equation is the amount of average annual rainfall. Difficulty in apply-

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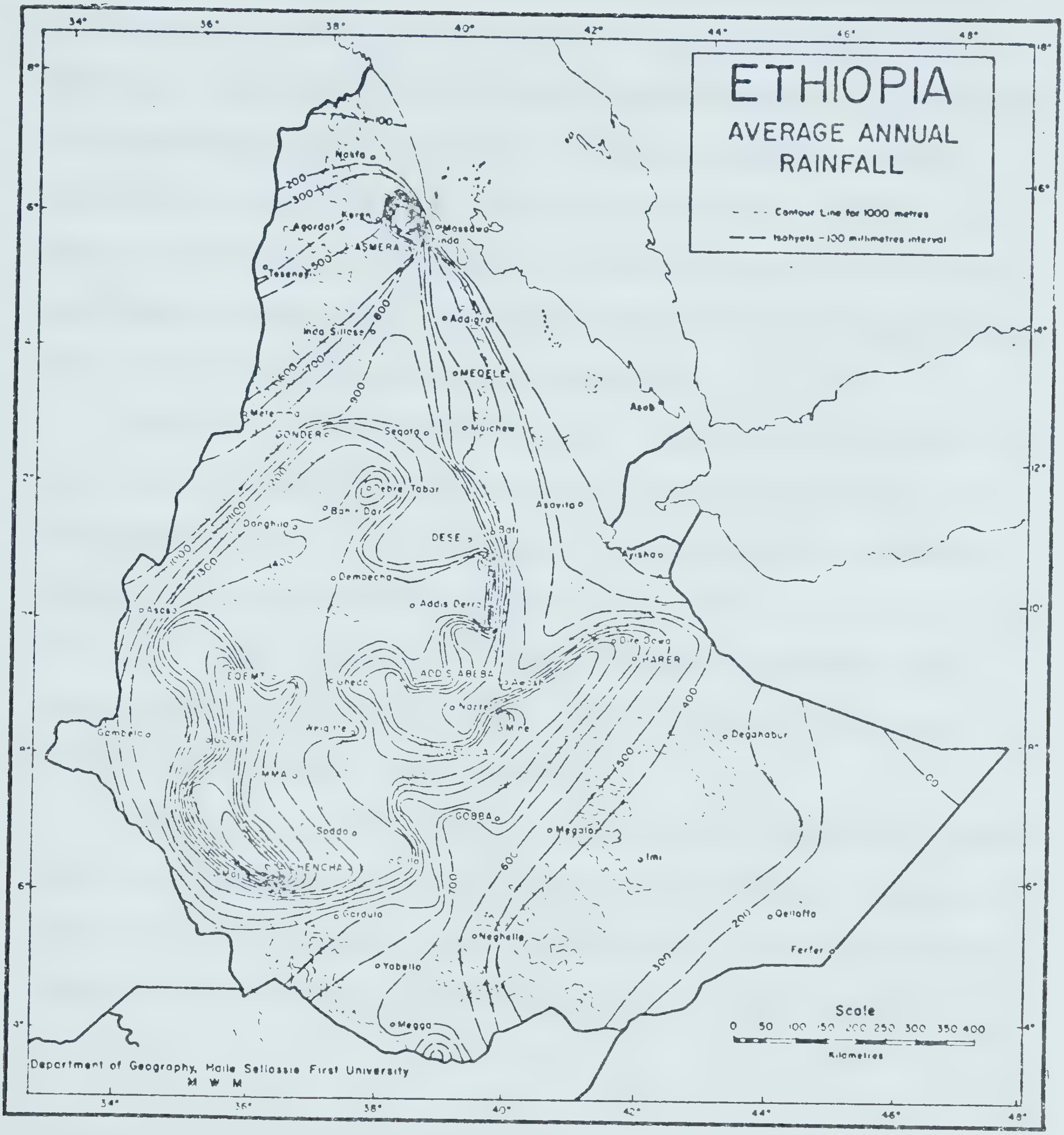
[1] For further detail on this point see Kebede Tatu, "Rainfall in Ethiopia," Ethiopian Geographical Journal, Vol. 2, No. 2 (December, 1964), pp. 28-36.



SOURCE: Mesfin Wolde Mariam, An Atlas of Ethiopia (Asmara: Poligrafico, Priv. Ltd., 1970), p. 26.

FIGURE 3.2

AVERAGE ANNUAL RAINFALL IN ETHIOPIA

ing the formula arises from lack of adequate rainfall data to estimate precisely the amount of average annual rainfall on a national basis. In a country where extreme rainfall patterns prevail and only a few scattered weather stations are available, average figures are bound to be very misleading. But since the intention here is to obtain some idea about magnitudes rather than precise estimation, the formula serves the desired purpose.

Assuming A = 900 mm or .9 m,[1] and H = 122,200,000 ha,[2] the total volume of rainfall available in an average year in Ethiopia will be approximately 109.98 million hectare-meters (ha-m) of water or about 1.099 trillion cubic meters. This would amount to 42,300 cubic meters or 42,300,000 liters per capita. This quantity of water is therefore potentially available each year.

Judging from the above figures, the country as a whole seems to receive adequate annual precipitation. However, the spatial and temporal distribution of this precipitation accounts for problems in availability of water supply.

Regional Distribution of Rainfall

There are wide variations in the spatial distribution

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[1] Extrapolated from isohytes shown on Figure 3.2.

[2] Imperial Ethiopian Government, Central Statistical Office, Ethiopia: Statistical Abstract, 1972, p. 7.

of rainfall in Ethiopia. For instance, the annual average at Assab on the Red Sea coast (elevation 11 meters) is 53.1 mm,[1] while the corresponding figure for Gore in the southwestern highlands (elevation 2,002 meters) is 2,506.1 mm.[2] While, in general, arid to semi-arid conditions tend to prevail in the peripheral lowlands and relatively wet conditions prevail in the highlands, considerable variations seem to exist within each of these broad physiographic regions (Figure 3.3). The southwestern highlands, for instance, receive considerably more rainfall than the central and northern highlands, although the latter have considerably higher elevations.

In Ethiopia altitude alone has traditionally been used to classify regions into climatic zones. This highly simplified approach is inadequate as it fails to fully explain why regions with the same altitude have different amounts of rainfall. Recently, more systematic studies have attempted to incorporate other determining variables in order to improve the explanation and prediction of the patterns of regional rainfall distribution in Ethiopia. Significant among these is Kebede Tatu's study,[3] which suggests that rainfall in Ethiopia is positively correlated

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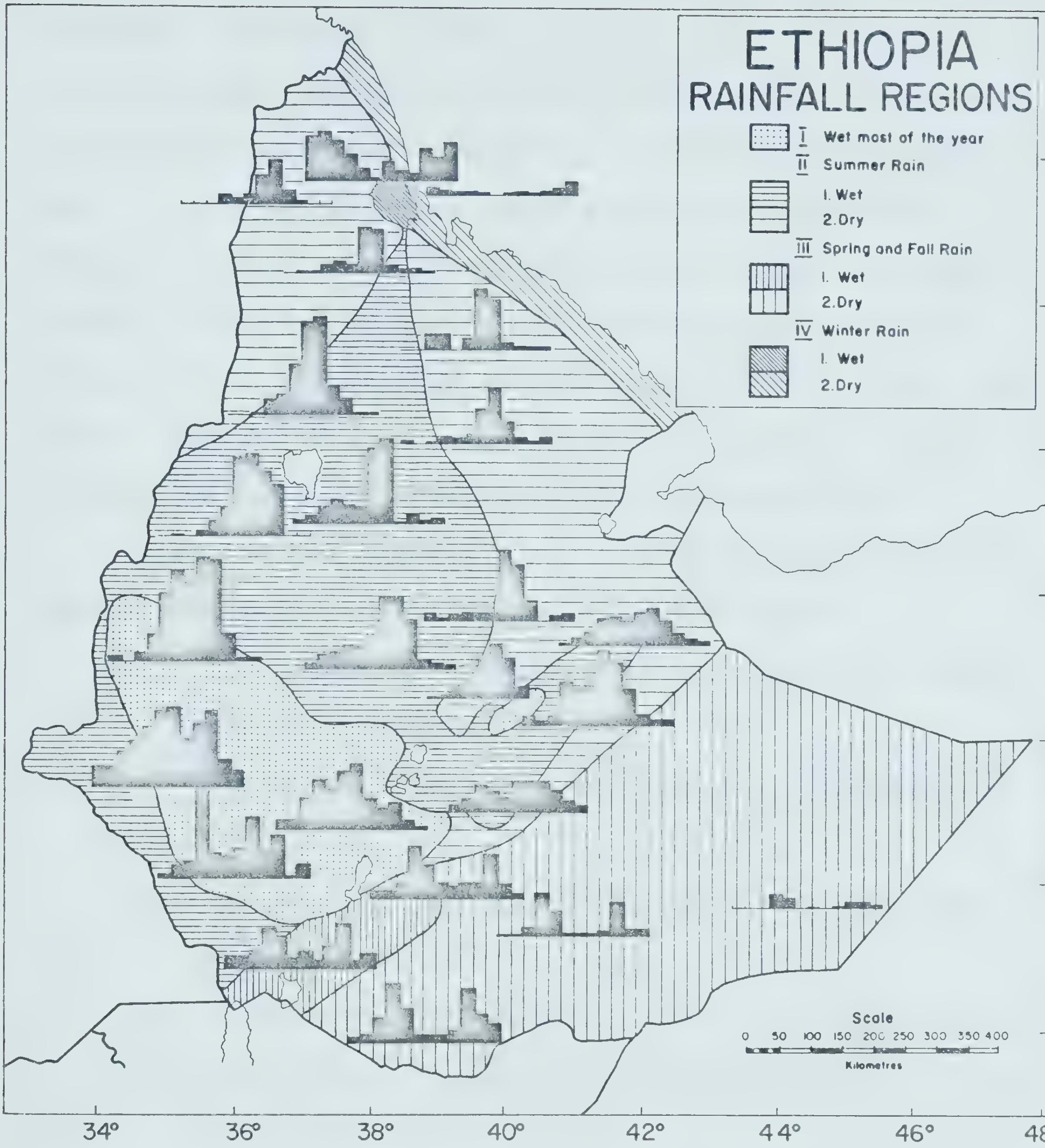
[1] Ibid., p. 10.

[2] Ibid.

[3] Kebede Tatu, "Rainfall in Ethiopia."



SOURCE: Mesfin Wolde Mariam, An Atlas of Ethiopia (Asmara: II Poligrafico, Priv. Ltd., 1970), p. 27.

FIGURE 3.3

REGIONAL DISTRIBUTION OF RAINFALL IN ETHIOPIA

with altitude and negatively correlated with longitude and latitude. According to the conclusion of this study, therefore, altitude remaining constant, the volume of rainfall in Ethiopia decreases from south to north and from west to east. This conclusion is amply supported by empirical evidence.[1] The influence of altitude on rainfall, other factors remaining constant, has also been established. Rainfall data recorded at different elevations in the Awash Valley indicate that the average annual rainfall increases by 60-70 mm for every 100 meter rise in elevation.[2]

Based on the results of his study, Kebede classified the country into nine different rainfall regions:[3]

1. The highlands of Shewa, Wallo, Begemedir, Gojam and Northwestern Wellega.
2. The western highlands of Illubabor, Wallega and Kefa.
3. The western and the northwestern lowlands and plains.
4. The Rift Valley (north of the lakes district).
5. The southern lowlands of Sidamo, Gemu Gofa, Kefa, and the Ogaden Lowlands.

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[1] Ibid.

[2] Carl F. Miller et al., Systems Analysis Methods for Ethiopian Agriculture (Menlo Park, California: Stanford Research Institute, 1968), p. 54.

[3] Kebede Tatu, "Rainfall in Ethiopia," p. 31.

6. The Red Sea coastal plains.
7. The highlands of Arussi, Bale and Harargie.
8. The Northern Denkel Plain.
9. The highlands of Tigre, Eritaria, Northern Wollo and Begemder.

This classification seems to coincide rather closely with an earlier classification by Huffnagel,[1] who partitioned Ethiopia into ten different rainfall regions.

The available evidence, therefore, clearly indicates that significant variations in rainfall exist among the various regions of Ethiopia. These variations seem to be adequately explained by the combined effects of altitude, longitude and latitude. As far as can be determined from the available information, most of the highland regions (i.e., regions 1, 2, 7 and 9 above) receive adequate amounts of rainfall for crop production while the lowland regions (i.e., regions 3, 4, 5, 6 and 8) are generally beset by scarcity of rainfall. The traditional pattern of agricultural practice has, therefore, closely followed the pattern of rainfall distribution. In the wet highland regions, mixed farming prevails, while in the dry lowlands, cattle raising tends to dominate.

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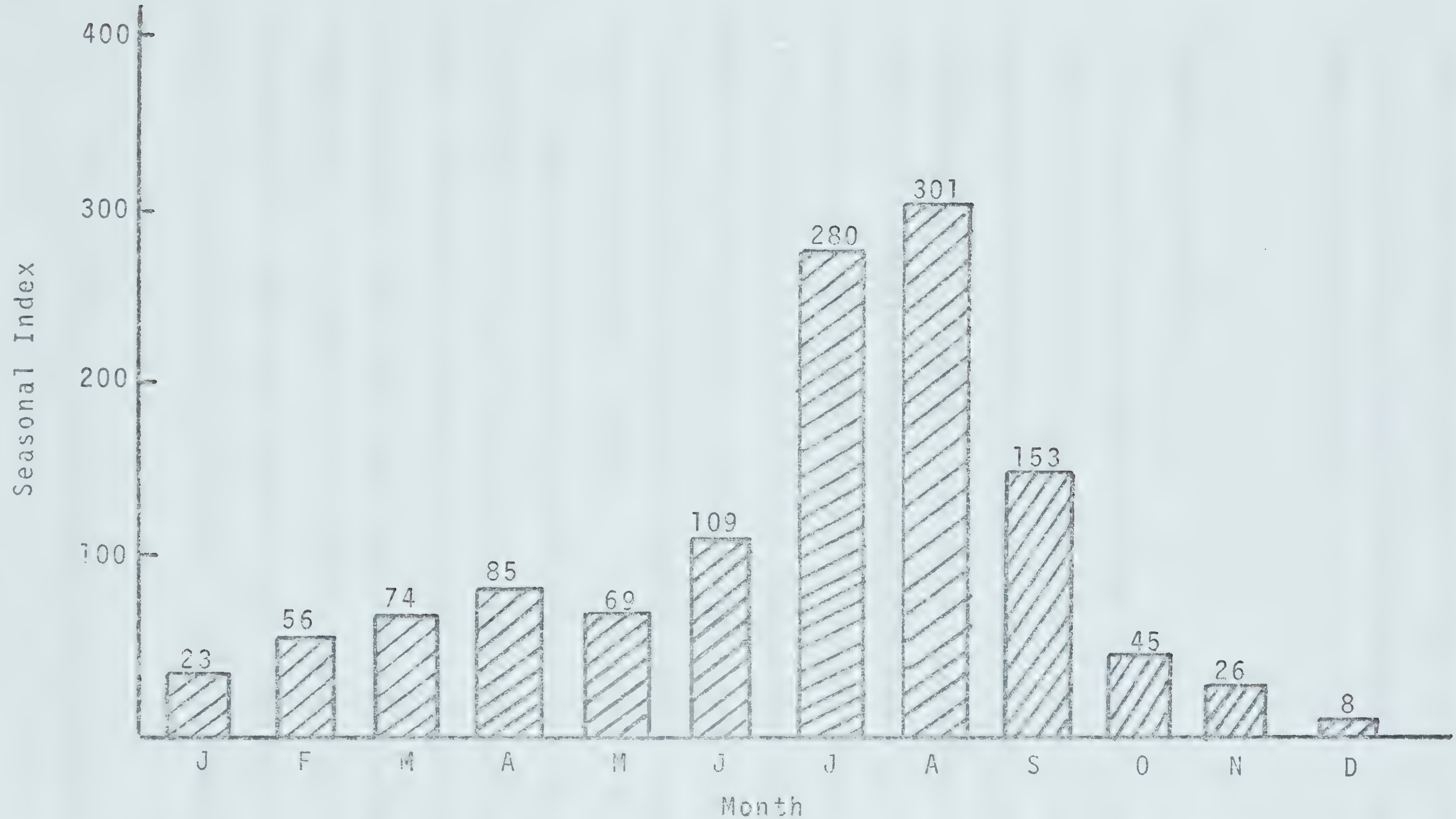
[1] H.P. Huffnagel, Agriculture in Ethiopia (Rome: F.A.O., 1961), p. 60.

Temporal Variation of Rainfall

The temporal variations (seasonal, interannual, and cyclical variations) of rainfall are also of vital importance to agricultural production. Rainfall is extremely seasonal in most parts of Ethiopia. Only in the western highlands of Illubabor, Wallega and Kefa does rain fall most of the year. The rest of the country is restricted to a short wet season which may occur at different times in different regions. To date very little is known about the cyclical behavior of rainfall in Ethiopia.

In this study an attempt was made to compute the seasonal index of rainfall in the central highlands (i.e., the region roughly corresponding to rainfall region 1 above) using the average of monthly data over a seven year period. The period of time for which data are available was not considered sufficient to warrant an analysis of the cyclical behavior. The result of the analysis is depicted in Figure 3.4.

The data analyzed indicates that about 70 percent of rainfall in the central highlands occurs between June and September, August being the month of highest rainfall. Some precipitation occurs between February and April, but this rainfall is generally unreliable. While the seasonal fluctuation of rainfall in Ethiopia as a whole is considerable, the interannual fluctuations of rainfall, particularly in the central highlands, appear to be rather small. It



SOURCE: Computed by author from data obtained from Imperial Ethiopian Government, Central Statistical Office, Ethiopia: Statistical Abstracts (Addis Ababa: CSO, 1968-1972 Issues).

FIGURE 3.4

SEASONAL MONTHLY INDEX OF SEVEN YEAR RAINFALL DATA IN THE CENTRAL HIGHLANDS OF ETHIOPIA

should nevertheless be emphasized that a more systematic study of the seasonal, trend, and cyclical variations of rainfall in Ethiopia needs to be conducted if the existing temporal patterns are to be fully understood.

Rainfall Intensity

Along with the regional distribution and seasonal variation of rainfall, the intensity of rainfall also has important implications for water supply and agricultural development in Ethiopia. Due to the generally mountainous nature of Ethiopia's topography, high rainfall intensities usually result in rapid run-off. The more rapid the run-off, the less chance for percolation and infiltration that would help build up the ground water stock. High rainfall intensities also precipitate erosion and are more likely to result in destructive floods.

Typically, the rains in Ethiopia fall in heavy showers and downpours, suggesting a very high intensity per unit of time. According to Huffnagel, intensities of between 60 and 70 millimeters per hour have been recorded in the central highlands.[1] The effects of high rainfall intensities are reflected in severe soil erosion and flooding of lower plains in most parts of Ethiopia. The associated loss of

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[1] H.D. Huffnagel, Agriculture in Ethiopia, p. 60.

agricultural output is believed to be considerable.

Surface Water Resources

Surface water resources in Ethiopia are, by and large, flow resources that are constantly renewed by precipitation. Consequently, different quantities of these resources become available at different times. The characteristic of such resources, as Ciriacy-Wantrup[1] points out, is that the flow without use, may increase or decrease continuously or discontinuously at either a constant or varying rate. Since there is no relationship between present and future flows, it should be possible to maintain use of surface water sources indefinitely as long as adequate precipitation continues.

In Ethiopia, three types of surface water sources can be distinguished: rivers and streams, freshwater lakes and ponds, and sea water. Freshwater lakes and rivers, constitute by far the largest sources of water supply for withdrawal uses in Ethiopia. Except for a limited amount of fishing, salt mining and navigation, Ethiopia has not made use of the waters of the Red Sea to any appreciable extent. While the direct use of water from the Red Sea for consumptive purposes is not possible at present because of

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[1] S.V. Ciriacy-Wantrup, Resource Conservation: Economics and Policies (3rd Edition: Berkeley: Division of Agricultural Sciences, University of California, 1968), p. 37.

its saline nature, it does represent an important potential source for supplying the water requirements of the coastal lowlands provided that low cost desalinization and conveyance technologies are available. Meanwhile, the present uses of the Red Sea can be expanded considerably with proper planning and investment.

Rivers and Streams

Ethiopia is endowed with a large number of rivers and streams. While many of the smaller streams carry water only during the season of heavy rains, practically all of the larger rivers have permanent flows. However, their discharge rates vary considerably, depending on the season. Maximum discharge rates of the large majority of rivers occur during the wet season of June-September, with the peak monthly discharge occurring in August, thus coinciding with the month of highest rainfall in the highlands.[1]

Average annual flows as well as the power and irrigation potential of the major Ethiopian rivers are shown in Table 3.1. The figures clearly indicate that practically all the major rivers of Ethiopia have considerable potential for either hydro-power or agricultural development. The

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[1] Unpublished data compiled by the Ethiopian Water Resources Commission over the past decade indicate that the highest mean discharge rates of the major rivers occurs during the month of August.

TABLE 3.1

POWER AND IRRIGATION POTENTIAL OF

MAJOR ETHIOPIAN RIVERS

River	Length Inside Ethiopia (km)	Average Annual Flow Discharge (Billions of m^3)	Estimated Irrigable Area Commanded (ha)	Estimated Power Potential (Millions of kwh)
Abay (Blue Nile)	800	53.0	440,000	24,900.0
Awash	1,200	5.4	200,000	1,304.0
Baro[1]	277	11.8	n.a.[2]	1,211.0
Genale[3]	480	10.3	n.a.	654.0
Mereb	440	1.9	n.a.	569.2
Omo	760	10.2	n.a.	4,595.9
Tekeze[4]	608	11.0	n.a.	5,047.7
Wabi Shebelle	1,000	10.5		7,044.6

[1] Includes the flows of Baro Akobo, Akobo and Chelo Rivers.

[2] Not available.

[3] Includes the flows of Juba, Dawa, and Gastro Rivers.

[4] Includes the flows of Atbara, Angreb and Gunda Rivers.

SOURCES: Imperial Ethiopian Government, Central Statistical Office, Ethiopia: Statistical Abstract, 1972, p. 7; Unpublished Data from National Water Resources Commission; and I.E.G. Ministry of Planning and Development, Regional Aspects of National Planning in Ethiopia: Part II, Appendix B.

largest Ethiopian river, the Abay, drains an area of approximately 30.55 million hectares[1] of which about 440,000 hectares are irrigable.[2] The average annual flow of the Abay River is estimated to be 53 billion cubic meters.[3] The average annual sediment load is estimated at 500 million tons. It has seven major tributaries, each contributing more than two billion cubic meters of water annually.[4]

The Wabi Shebelle River is probably the second largest river in the country, with an annual flow of 10.5 billion cubic meters.[5] The Wabi Shebelle Basin is estimated to cover 200,000 square kilometers or approximately 20 million hectares.[6] Although the extent of the irrigation potential of this river has not been established, its potential for hydro-power development (Table 3.1) appears to be considerable.

Of the major rivers of Ethiopia, the Awash River is

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[1] U.S. Bureau of Reclamation, Land and Water Resources of the Blue Nile Basin, p. 1.

[2] Ibid., pp. 213-339.

[3] Unpublished data from the National Water Resources Commission.

[4] Ibid.

[5] Ibid.

[6] Imperial Ethiopian Government, Ministry of Planning and Development, Regional Aspects of National Planning in Ethiopia, Part II, Appendix B, p. 6.

very unique in many respects.[1] It is the only major river in the Ethiopian Rift Valley, and it is the only one flowing due east. Most important of all, unlike all the other major rivers which eventually leave Ethiopian territory, the Awash River runs its entire course within Ethiopia. The Awash River begins its 1,200 kilometer journey in the central (Shewan) highlands of Ethiopia and flows in a northeasterly direction to its final destination in Lake Abe in northeastern Ethiopia. Its basin covers an area of about 70,000 square kilometers, or approximately 7 million hectares, and has an irrigable area of about 200,000 hectares.[2] Approximately 151.8 thousand kilowatt hours of electricity is presently produced annually in the Awash Basin.

The regional distribution of Ethiopia's rivers is depicted on Figure 3.5. All the major rivers originate in the high rainfall areas of the highlands and flow toward the more arid lowlands in the west and east. Since the headwaters of most of the major rivers are mountain springs which depend on available rainfall to replenish their supply, the proper management and protection of headwaters is of

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[1] For further elaboration of this point see: Mesfin Wolde Mariam, "The Awash Valley: Trends and Prospects," Ethiopian Geographical Journal, Vol. 2, No. 1 (June, 1964).

[2] Food and Agriculture Organization, Survey of the Awash Basin, Volume V: Irrigation and Water Planning (Rome: F.A.O., 1965), p. 3.

SOURCE: Mesfin Wolde Mariam, An Atlas of Ethiopia (Asmara, Ethiopia: Poligrafico Priv. Ltd., 1970), p. 14.

FIGURE 3.5

THE DRAINAGE SYSTEM OF ETHIOPIA

crucial importance in the maintenance and regulation of the flow discharge of Ethiopia's water-courses.

It is perhaps significant to note that, while no exotic rivers flow into Ethiopia, the important Ethiopian rivers, with the exception of the Ghibe and the Awash, flow across international boundaries to provide crucial supplies of water to the neighbouring countries of Somalia and the Sudan.[1] This condition has led some experts to dub Ethiopia the "water tower of Northeast Africa."[2] The implication of the foregoing situation to future water resource development in Ethiopia is, of course, far-reaching. For one thing, it indicates that Ethiopia's water supply strictly depends on the amount of rain that falls within the geographic boundaries of Ethiopia. On another plane, it implies that large-scale river basin development schemes that have the potential to affect the flow of some of the major rivers may have international repercussions.

The latter point seems to be of little relevance at this point as it is difficult to anticipate river basin development schemes in the foreseeable future that will significantly alter the flow of Ethiopia's major rivers. The first point, however, is significant in that it correctly

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[1] Mesfin Wolde Mariam, <u>An Atlas of Ethiopia</u>, p. 14.

[2] C.R.K. Prashar, "Crop Water Use Studies in Ethiopia," <u>Supplement to the Journal of the Association for the Advancement of Agricultural Sciences in Africa</u>, Vol. 2, Supplement I (August, 1973), p. 183.

indicates that the availability of water in Ethiopia depends on how successfully she protects, develops and utilizes her watersheds.

Lakes and Ponds

The second type of surface sources of water are lakes and ponds. Of significant interest among Ethiopia's lakes are the so-called Rift Valley Lakes. These are a string of six lakes extending from southwest Ethiopia along the Rift Valley to the heartland of central Ethiopia. The significance of these lakes lies in their strategic location from the standpoint of agricultural development, wildlife conservation and the development of water based recreation.

Lake Tana, located in northwest Ethiopia, is the largest Ethiopian lake and is also the source of the River Abay, Ethiopia's largest river. Lake Tana has an estimated water storage capacity of approximately 21.49 billion cubic meters (Table 3.2). The storage capacity of Lake Abaya, the largest of the Rift Valley Lakes and the second largest lake in the country, is estimated to be about 9.9 billion cubic meters. The total water storage capacity of the major Ethiopian lakes is estimated to be in the order of 55.05 billion cubic meters (Table 3.2).

In addition, Ethiopia is endowed with a number of smaller lakes and numerous ponds, all of which serve as actual or potential sources of water. Although expected to

TABLE 3.2

APPROXIMATE SIZE AND STORAGE CAPACITY
OF ETHIOPIAN LAKES

Name of Lake	Altitude (m)	Area (km^2)	Estimated Water Storage Capacity (Billions of m^3)
Abaya	1,268	1,160	9.952
Abiyata	1,573	205	1.894
Ashenge	2,409	20	0.330
Awasa	1,708	129	0.851
Bishoftu	--	--	--
Chamo	1,235	551	3.636
Hayk	551	35	0.531
Koka	--	--	--
Langano	1,585	230	6.982
Shala	1,567	409	6.485
Tana	1,840	3,600	21.492
Ziway	1,846	434	1.145
Total Storage Capacity			55.0504

SOURCE: Imperial Ethiopian Government, Central Statistical Office, Ethiopia: Statistical Abstract, 1972 (Addis Ababa: Central Statistical Office, 1972), p. 7. The storage capacity is estimated by the author on the basis of area and average depth.

be considerable, the full potential of Ethiopia's lakes and ponds as sources of water for agricultural and industrial uses has not yet been systematically assessed. Presently most of these natural reservoirs serve as main sources of livestock and domestic water supply for the population living adjacent to them. Despite the existence of a great need for a reliable source of farm water supply in Ethiopia, man-made farm ponds and dugouts are conspicuously absent from Ethiopian farmsteads.

Ground Water Resources

Very little is known about ground water resources in Ethiopia. Although experience indicates that bore holes and wells are common sources of water supply for domestic and livestock use in many parts of Ethiopia, no systematic study regarding the occurrence of ground water, its hydraulic characteristics, the distribution of wells and their yields has yet been made. Even less is known about the potential of ground water as a source of irrigation water.

However, it appears reasonable to postulate the existence of significant quantities of ground water in Ethiopia on the basis of the nation's relatively high mean annual rainfall and the structural formation of the land. Nevertheless, until sufficient scientific investigation is conducted, not much can be said about the ground water resources of Ethiopia, except perhaps that this is a resource that

the country can ill afford to neglect. It must also be pointed out that this lack of information limits the choice of water development projects to surface water development only and surface sources are not always the most economical to develop. As well, public water policy should recognize the close interrelationship that exists between surface and ground water resources and consequently should consider the possibility of integrating surface and ground water development.

Water Demand in Ethiopia

Attention will now be directed to the evaluation of demand for water in Ethiopia. Four types of sectoral decmands for water may be recognized in Ethiopia -- household demand, agricultural demand, industrial demand, and the demand for flow uses of water. Each of these sectoral demands will be discussed in the following section, but first a concise theoretical description of water demand will be presented.

Water is both a consumer and a producer good. As a consumer good it is used directly by households to satisfy water-related needs. Consumers derive satisfaction from water not only when they drink it or when they use it for daily cooking, cleaning and sanitation, but also when they go outdoors to enjoy water-based recreation.

As a scarce consumer good, fresh water is subject to

the general laws of consumer demand. Therefore, the same general factors that influence the demand for other consumer goods can be expected to influence the demand for water. Given the tastes and preferences of consumers, particularly as regards their food preparation habits and life-styles, a consumer demand function for fresh water may be postulated as follows:

$$F(w) = (P_w, Y, P_o), \quad f_{P_w} < 0, \; f_y > 0, \quad P_o \lessgtr 0 \qquad (3.1)$$

where $F(w)$ = quantity of water demanded per unit of time,

P_w = price of water per unit of time,

Y = consumer income per unit of time,

P_o = price of other goods per unit of time.

The total quantity of water consumed by all the consumers of a given location at any given time can then be derived by summing the quantities demanded by consumers at that specific time.

As a producer good, water has the capability, in proper combination with other inputs, to produce intermediate or final consumer goods. Water or water services are demanded in a wide range of productive activities, including agriculture, industry, and the service sector. It would not be an exaggeration to say that it is difficult to find an agricultural or industrial process that does not use water

in one form or another.

As a factor of production, water has a derived demand and is subject to the general laws of factor or input demand. The demand function for water as an input may, therefore, take the following form:

$$F(w) = f(P_W, P_Q), \quad f_{P_W} < 0, \quad f_{P_Q} > 0 \qquad (3.2)$$

where $F(w)$ = the quantity of water input demanded per unit of time,

P_W = the price of water per unit of time,

P_Q = the price of output per unit of time.

At equilibrium, the price of water (P_W) must be closely related to the marginal value product of water. According to the behavioral relationships expressed in equation (3.2), the demand for water as a factor of production is negatively related to the price of water and positively related to the price of the output that it helps produce. Analogous to the theory of consumer demand, the relevant individual firm demands must be added to obtain the total quantity of water demanded by the firms operating in a given locality at any given time.

Having briefly described the theoretical aspects of demand for water, the characteristics of water demand in Ethiopia will now be investigated. An effort will be made

to explain the various classes of water demand in Ethiopia, and to provide an overall picture of the existing level of consumption. More specifically, household demand, agricultural demand, industrial demand, and demand for water services such as hydro-power generation, navigation and recreation will be briefly discussed.

Household Water Demand

In order to put the nature and characteristics of household demand for water in Ethiopia in proper perspective, it is essential to distinguish between rural and urban households.

A. Rural Household Water Demand

Most Ethiopians live in scattered rural villages. The village water supply usually comes from a nearby stream or an undeveloped spring. The required daily supply is carried home by the housewife in a big clay jar, and it is not uncommon for her to make two or more trips daily to draw water from the local stream. Common observation seems to indicate that most rural housewives travel a distance of over one mile to obtain their daily water supplies. In some areas, notably in the semi-arid lowlands, people have been known to travel a day's journey to draw water. Under these circumstances, it is obvious that water is not a marketable commodity and hence it would appear superfluous to speak of

demand for water in the rural areas of Ethiopia. But since demand is a price-quantity relationship, such a relationship can be established by imputing value to the time and effort expended by the housewife in drawing water. In another sense, the time spent by the housewife in drawing water does have an opportunity cost[1] since larger units of water can only be consumed if the effort required to obtain them is small. A price-quantity relationship can be established (Figure 3.6) by treating the opportunity cost of obtaining water as the price of that quantity of water.

As illustrated in Figure 3.6, a demand schedule can be established for rural household water consumption by relating the imputed value of effort expended to obtain water and the quantity of water consumed. Common observation in rural Ethiopia seems to indicate that villagers who have to travel longer distances to draw water are more frugal in their use of water than those who have the source of supply close to the village site. Differences in consumption levels can also be observed within the same household in different seasons of the year. During the rainy season, when rain water is available close to the settlement, quan-

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[1] To the extent that there is unemployment or underemployment among rural housewives, the opportunity cost of a housewife's labor spent in drawing water may be zero. But experience and common observation seem to indicate that despite the existence of unemployment and underemployment in the general labor force, housewives, particularly rural housewives in Ethiopia, represent a fully employed sector of the population.

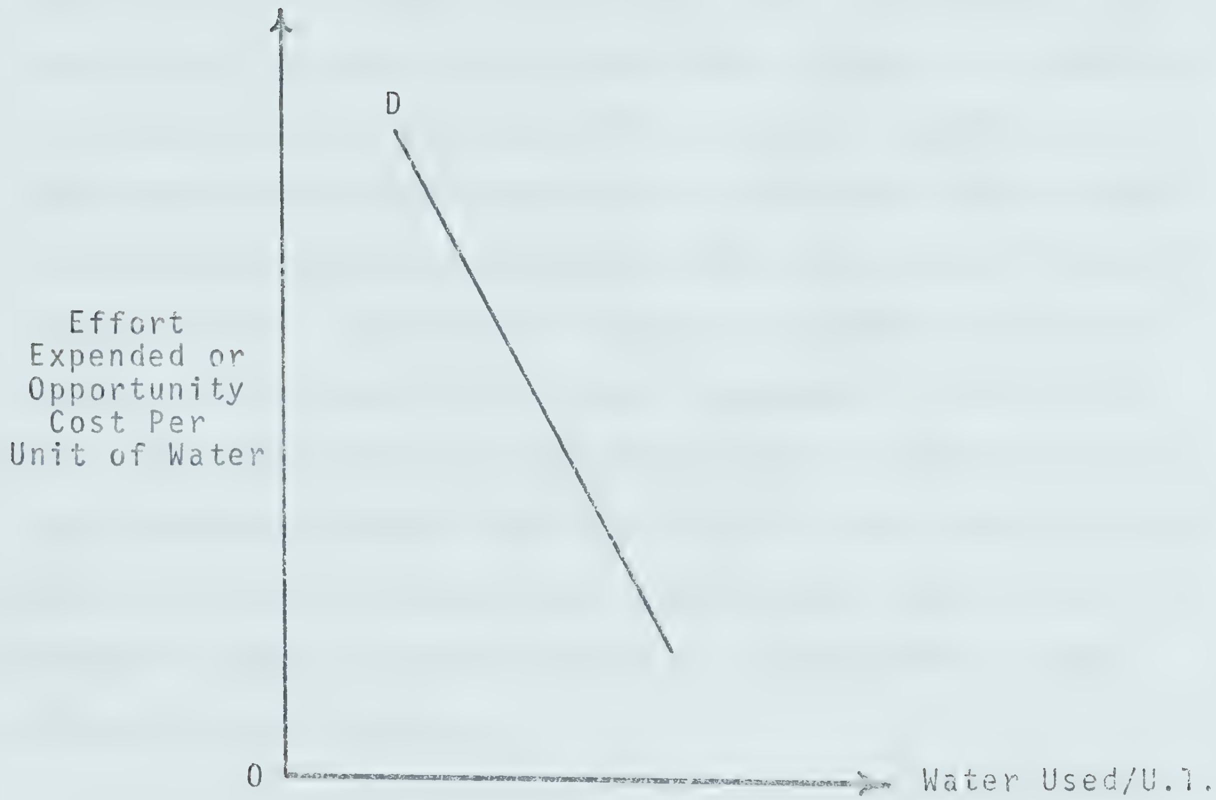

FIGURE 3.6

HYPOTHETICAL WATER DEMAND SCHEDULE

tity consumed tends to increase as compared to the dry season when more effort is required to obtain a unit of water.

Income is also a factor in the quantity of water consumed because relatively well-to-do families have better facilities for drawing and storing water. They can also afford domestic help whose job, among other things, is to draw water. Wealthier families may even have private wells close to the village, with a resultant increase in quantity of water consumed. Consequently, the total quantity of water demanded by rural households in Ethiopia can be determined by horizontally summing the individual rural household demand curves. There is at present no estimate available to indicate the quantity of water consumed by households. But assuming a per capita consumption of 11 liters per day[1] and an estimated rural population of 23.76 million (i.e., 90 percent of the estimated total population), total rural household water consumption will be in the order of 95.4 billion liters per year.

B. Urban Household Water Demand

Water supply systems in most major urban centers in Ethiopia are owned and operated by municipal authorities. Water Supply in the smaller unincorporated towns, however,

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[1] This quantity has been recommended by an F.A.O. team in a recent study on rural household consumption in Libya. See F.A.O., Development of Tribal Lands and Settlement Projects in Libya: Volume I, General Report (Rome: F.A.O., 1969), p. 90

is the responsibility of the Ministry of Interior.[1] One outstanding characteristic of urban water supply systems in Ethiopia is the fact that a large majority of the urban dwellers purchase their daily water supply from public outlets. Very few households have house connections and still fewer households enjoy the conveniences of running water, indoor toilet and bath facilities.

The rates paid by consumers seem to vary according to the distribution system used and the geographic location of the city. For instance, the price paid at the public outlets varies from approximately E $0.005/liter in Addis Ababa to E $0.008/liter in Dire Dawa, a city located in the eastern lowlands where water is very scarce.

The effect of family income on water consumption is also much more pronounced in the urban centers than in the rural areas. The urban high income groups usually have such modern conveniences as running water, indoor toilet, bath and laundry facilities, all of which add significantly to the water consumption level of the households. In contrast, the lower income class, who constitute the large majority of urban dwellers, do not enjoy any of these conveniences and consequently their water consumption level is comparatively lower.

The level of urban per capita water consumption in

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[1] Imperial Ethiopian Government, Third Five Year Development Plan, 1968-1973, p. 115.

Ethiopia is very low compared to consumption levels elsewhere in the world.[1] Urban per capita water consumption does not exceed 17 liters/day. Assuming a per capita consumption of 17 liters/day and a total urban population of 2.6 million, total water consumption in the urban areas of Ethiopia would be in the order of 16.13 billion liters per year. Urban demand is, of course, likely to increase with increases in population, urbanization and per capita income.[2]

Household water demand, however, accounts for a very small proportion of total water demand in Ethiopia. The major water consuming sectors are the productive sectors of the economy. The demand for water as a producer good by far exceeds consumer demand. The water demands of agriculture, industry and service sectors are presented next.

Agricultural Water Demand

Water is an important input in the agricultural production process. Both crop and livestock production processes require adequate water supplies for optimum yield. For

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[1] For further comments and background information on this point see B.H. Dieterich and John M. Anderson, Urban Water Supply Conditions and Needs in Seventy-Five Developing Countries, World Health Organization Public Health Papers No. 23 (Geneva: W.H.O., 1963).

[2] See Terrence R. Lee, Residential Water Demand and Economic Development (Toronto: University of Toronto, Department of Geography, University of Toronto Press, 1969), for an interesting perspective on the relationship between residential water demand and economic development.

instance, it has been estimated that in the temperate zone about 2,000 liters of water are required for every kilogram of wheat harvested, 1,200 to 1,600 liters of water per kilogram of harvested green grass, about 4,800 liters of water per liter of milk, and about 29,600 liters of water for one kilogram of beef.[1] It has been suggested that because of higher evapotranspiration, twice as much water is required in tropical areas as in temperate areas.

At present almost the entire crop production system in Ethiopia consists of dryland farming. Only a small portion of the cultivated area is under irrigation. Recent estimates put the figure at 68,000 hectares,[2] about 50 percent of which are located in the Awash Valley. The presently irrigated area therefore represents approximately 10 percent of the identified irrigable areas in the country, and prospects for future identification of more irrigable land when existing and future water resource surveys are completed appear very good. Irrigated area as a percentage of currently cultivated land area, however, is a negligible 0.005 percent.

Under existing conditions, therefore, Ethiopia's agricultural water requirement is met by rainfall and soil

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[1] George Borgstrom, World Food Resources (New York: INTEXT Educational Publishers, 1973), p. 64.

[2] Imperial Ethiopian Government, Third Five Year Development Plan, 1968-1973, p. 110.

moisture. However, it is very doubtful that the existing and future food demands of the rapidly increasing population can be met by relying on dryland farming alone. The dryland farming system is already under severe strain, and relief must come from, among other methods, expansion of irrigation, for which the country already possesses sufficient potential.

Agricultural water demand in Ethiopia, therefore, consists of an emerging demand for irrigation water and the provision of water for livestock use. Water demand for both of these purposes is a derived demand and hence depends on the marginal value product of water in these uses. In either of these activities, water is considered efficiently allocated if it is applied up to the point at which its marginal value product equals its supply price. It should be kept in mind that subsidized or otherwise unrealistically set water rates are not an adequate reflection of the true supply price of water. If economic efficiency is to be the main criterion for allocating water in productive activities, it is essential that the price charged must take into account the full cost of making the specified quantity of water available at the point of use.

Very little is known about the efficiency of water use in the irrigated areas of Ethiopia. Since the producers are responsible for developing their own water supply, they do not pay any water charge at present. However, there are plans, at least in the Awash Valley, to construct diver-

sion dams and eventually provide water to farm headgates. If and when this plan materializes, a water charge of E $0.005 per cubic meter has been suggested.[1] Whether such a rate takes into account the full cost of supplying the indicated quantity of water to the farm headgate is not clear. Research is urgently needed to establish the real cost and the value of the marginal product of irrigation water under various cropping patterns. Determination of the overall efficiency of water utilization in the areas which are presently irrigated is an essential step in the process of formulating long run irrigation policy.

The existing level of water used for irrigated crops represents only a small percentage of the potentially available irrigation water supply. Current water use amounts to approximately 612,000 cubic meters per annum as compared to about 574 million cubic meters proven to be available for irrigation in the Abay and Awash River Basins.[2]

As in crop production, the availability of an adequate and clean water supply is a crucial factor in livestock pro-

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[1] M.E. Quenemoen, Potential Returns from Commercial Farming Systems in Three Areas of Ethiopia, Experiment Station Bulletin 56 (Dire Dawa, Ethiopia: HSIU, College of Agriculture, 1968), p. 44.

[2] For information on irrigable area in the Abay Basin see: United States Department of the Interior, Bureau of Reclamation, "Appendix VI: Agriculture and Economics," Land and Water Resources of the Blue Nile Basin, and for corresponding information on the Awash Basin, see: Food and Agriculture Organization, Survey of the Awash River Basin, Vol. I: General Report (Rome: F.A.O., 1965).

duction. The need for water arises not only from the direct consumption requirements of the stock but also from the necessity to produce supplemental forage to be used by the stock during the dry season. The demand for water in either of these uses is a derived demand; it is derived from the demand for livestock and livestock products. Consequently, the demand for water for these purposes can be expected to increase if the demand for livestock and their products increases.

Presently, there is no irrigated forage production in Ethiopia and livestock as a rule subsist on native range and unimproved pasture. Most native pastures are of low carrying capacity. There is also evidence of widespread overgrazing throughout the country. Among other things, therefore, lack of adequate feed resources and shortage of water, particularly during the long dry season, seem to have kept livestock output at a very low level.

In 1974, the daily water requirement of the livestock population was estimated to be about 677 million cubic meters (Table 3.3). Undoubtedly, future attempts to improve livestock output in Ethiopia through improvement of fodder and provision of water as a free choice would substantially raise the average daily consumption of water. It is therefore realistic to expect an increase in demand for livestock water supply in the years ahead.

TABLE 3.3

ESTIMATED ANNUAL WATER REQUIREMENTS OF ETHIOPIAN LIVESTOCK, 1974

Type of Livestock	Estimated Numbers	Estimated Average Daily Requirements (Liters/Animal)	Total Daily Requirements (Millions of Liters)	Total Annual Requirements (Millions of Cubic Meters)
Cattle	24,663,000	16	394.61	144.03
Sheep	22,320,000	4	89.28	32.59
Goats	17,322,000	4	69.29	25.29
Poultry	52,900,000	1/2	26.45	9.65
Donkeys	3,945,000	9	35.50	12.96
Mules	1,451,000	15	21.76	7.94
Horses	1,453,000	15	21.80	7.96
Camels	1,001,000	19	19.02	6.94
Swine	19,000	4	0.08	0.03
Total			677.79	247.39

SOURCES: [1] Type and Number of Livestock. Food and Agricultural Organization of the United Nations, Production Yearbook, 1974 (Rome: F.A.O), pp. 193-202.

[2] Daily water consumption requirement: F.A.O., Development of Tribal Lands and Settlement Projects in Libya: Volume I, General Report (Rome: F.A.O., 1969), p. 90.

Industrial Water Demand

Many industrial processes require water either directly in their manufacturing processes or for cooling, sanitation, and waste disposal purposes. The industrial sector in Ethiopia is largely composed of such heavy water using industries as food processing, beverage and textile manufacturing, and sugar refining. However, since the level of industrialization in Ethiopia is very low at present, total industrial water demand does not amount to much compared to the other classes of water demand. Future industrial water demand, however, can be expected to increase significantly as efforts for further industrial expansion are intensified.

Demand for Flow Uses of Water

In addition to the above withdrawal demands, Ethiopia's water resources are used for flow uses such as hydro-electricity generation, navigation and recreation. The extent to which flow uses are important to Ethiopia can be reckoned by considering the figures in Table 3.4. Since 1967 over 70 percent of Ethiopia's electric energy has come from hydro sources. It is interesting to note that the existing hydro-electricity production of 307.48 million kwh per annum is less than 5 percent of the total estimated hydro-power potential of the major Ethiopian rivers (see Table 3.1). While none of Ethiopia's rivers, except a small

TABLE 3.4

ELECTRIC ENERGY PRODUCTION IN

ETHIOPIA, 1965-1972

Year	Hydro ('000 kwh)	Thermal ('000 kwh)	Total	Hydro as Percent of Total
1966	146,000	106,242	252,242	57.88
1967	210,256	84,237	294,493	71.14
1968	233,477	89,416	322,893	72.31
1969	240,008	100,756	340,764	70.43
1970	258,759	108,880	367,639	70.38
1971	299,575	116,620	416,195	71.98
1972	307,480	123,413	430,893	71.36

SOURCE: Imperial Ethiopian Government, Central Statistical Office, Ethiopia: Statistical Abstract, 1972 (Addis Ababa: Central Statistical Office, 1972), p. 59.

stretch of the Baro River in western Ethiopia, are navigable, their potential for recreation and aesthetic purposes is immense.

The important point that emerges from this quantitative appraisal of Ethiopia's water resources is the marked possibility that demand in all sectors will increase significantly in the years ahead. Although the potentially available sources of water supply are considerable, proper planning and sufficient investment will be required to meet the expected increase in demand.

Water Quality in Ethiopia

An important part of a nation's water resource appraisal involves quality considerations. Various types of water uses require a specified quality of water. For instance, household water supply must be free of soluble salts, disease-causing organisms and objectionable odors and tastes. Irrigation also requires water with no or very low salinity, while industrial processes require specified quality levels depending on the type of manufacturing and the water's specific function in the manufacturing process. Water supply sources, whether surface or ground, must therefore meet acceptable quality standards based on the purpose for which they are intended.

The level of industrialization in Ethiopia has not reached the point where industrial pollution is a major

concern. However, some pollution problems do presently threaten the nation's water resources. The three main sources of water pollution in Ethiopia are: human or domestic waste, agricultural pollutants and natural sources.

Pollution from human and domestic waste arises from the lack of adequate waste disposal systems in both the urban and rural areas of Ethiopia. The absence of proper and sanitary human waste disposal facilities has generally led to the use of open space for such purposes. Unfortunately, wastes so disposed are often carried into streams and lakes and consequently end up dangerously contaminating the sources of water supply. This practice seems to have contributed to the spread of a wide range of waterborne diseases, many of which are endemic in Ethiopia.

Although the use of agricultural chemicals is very limited in Ethiopia, agricultural activity still remains a considerable source of water pollution. The most serious problem in this regard is soil erosion. The mountainous terrain of the Ethiopian highlands, where the major farming activity is located, and the traditional farming practices that dangerously expose the soil to heavy water and wind erosion have combined to produce one of the most heavily eroded regions in the world. Therefore the Ethiopian farmer not only contributes to the annual loss of tons of productive soil but also causes streams, lakes and reservoirs to be degraded and silted up at an accelerated rate.

Aside from man's intervention in the environment,

nature also contributes to the impairment of water quality in Ethiopia. Depending on the biological, chemical and physical properties of the strata over which water passes, it accumulates, either in dissolved or suspended form, various substances that significantly alter its original properties. The presence of these contaminants in the water course can impair the quality of the water so as to make it unfit for direct use for a wide variety of purposes.

Salinity, for instance, arises from the presence of large quantities of salts that have been dissolved in a particular body of water. The salt is picked up as water flows over saline soils and geological formations with high salt content. Such contamination is a common occurrence both in surface and ground water sources and is particularly severe in arid and semi-arid regions.

In Ethiopia, salinity is a particularly serious problem in the semi-arid lowlands. Although most of the rivers that originate in the highlands can be expected to have low salt content in their upper reaches, salinity tends to increase as the rivers descend to the lower plains, where rainfall is scanty and the rate of evapotranspiration is relatively high. The salinity problem has very serious implications for the development of irrigation in the semi-arid lowlands of Ethiopia. Not only is water over a specified level of salt concentration not acceptable for irrigation, but lack of proper and adequate drainage causes salts to accumulate on irrigated fields. If adequate drainage

and occasional flooding of fields with sufficient quantities of water to wash out the accumulated salt are not provided, yields may eventually decline and subsequently lead to the permanent abandonment of the fields. History unequivocally provides many instances of cases where civilizations based on irrigation, for example, the early civilization of the Middle East, perished owing to salinity build-up. Fortunately, adequate provisions can be made to combat this potential problem when planning irrigation development. Among such provisions are the designing of adequate drainage facilities, the occasional flooding of fields and the inclusion of salt loving crops in the rotation program.

In planning water development programs, therefore, it is vitally important to consider not only the quantity but also the quality aspects of water. Measures for reducing existing pollution and safeguarding against future pollution should be an integral part of all water development plans.

CHAPTER IV

DESCRIPTION OF THE STUDY AREAS

The theoretical and conceptual discussions in the preceding chapters have demonstrated that water resource development has significant potential as a source of agricultural output growth in Ethiopia. More specifically, it has been suggested that investment in agricultural water supply projects can make substantial contributions to the expansion of food production and rural employment. Nevertheless, in order to properly assess the potential economic impact of water development in Ethiopia, it is necessary to make an intensive empirical study. Accordingly, two study areas were selected for conducting detailed empirical investigation (see Fig. 4.1).

The first study area selected is the Megech River area. This area is situated in the Abay River basin and encompasses approximately 5,890 hectares of irrigable land. The area is fairly typical of the Ethiopian highland plateau, with its characteristic mixed subsistence farming, moderately cool temperature and distinct wet and dry seasons. The second project area is the Kesem River area. It is located in the Middle Awash Valley, and covers approximately 5,650 hectares of irrigable land. The Kesem River area is fairly representative of the dry lowlands of

SOURCE: Ethiopian Mapping and Geography Institute.

FIGURE 4.1

ETHIOPIA: RIVER BASIN REGIONS

Ethiopia. The project area is generally characterized by high annual average temperatures, normally low and frequently unreliable rainfall and a primary economy based on nomadic pastoralism.

Besides being fairly typical of their respective regions, these two areas offer special opportunities for careful and detailed economic analysis because as part of the Blue Nile[1] and Awash River Basin[2] Surveys, their agronomic characteristics and physical potentials have been fully documented. This chapter, therefore, brings together basic information concerning the specific location, soils and climate, existing agricultural practices, transportation and market outlets of each of the project areas. A brief description of the project proposed for each region is also presented.

Megech River Project Area

Location

The Megech River study area is located in the Abay River Basin, slightly northeast of Lake Tana. The center

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[1] United States Department of Interior, Bureau of Reclamation, Land and Water Resources of the Blue Nile Basin.

[2] Food and Agriculture Organization, Survey of the Awash River Basin, Vol. I: General Report; Vol. II: Soils and Agronomy; Vol. III: Climatology and Hydrology; Vol. IV: Water Storage and Power Development; and Vol. V: Irrigation and Water Planning.

of the project area is fixed at approximately 12° 25' north latitude and 37° 30' east longitude, and is roughly 20 kilometers due west of the Addis Ababa-Gondar national highway. The area lies at an elevation of 1,830 meters (6,020.7 ft.). The land area being considered for development is 5,890 hectares adjacent to and commanded by the Megech River.

Soils, Topography and Climate

Although a wide variety of soils prevail in the Megech River Project area, two types of soils, grumusols and latosols, dominate.[1] These soils are quite characteristic of the soils of the Ethiopian highlands. As in many parts of the highland plateau, the grumusols make up a significant percentage of the lands of the Megech River Project area. The grumusols are dark grey in color and have a high percentage of clay, a high coefficient of expansion and contraction, and a low organic matter content. They generally exhibit a marked tendency to crack deeply and widely during the dry season. They have a pH of between 5 and 7. Although they have poor drainage, they are non-saline and under good soil management can be made to produce well with irrigation.[2]

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[1] United States Department of Interior, Bureau of Reclamation, "Appendix V: Agriculture and Economics," Land and Water Resources of the Blue Nile Basin, pp. 2-3.

[2] Ibid.

The latosols are generally red clay soils found in gently sloping areas. They constitute a smaller portion of the project area. As a rule they are finer in texture, more acidic, more water receptive but less fertile than the grumusols.

The topography of the area varies from relatively flat plain on the southern edge to gently sloping high ground in the northern portion. Lying at an altitude of 1,830 meters above sea level, the area enjoys a "woina dega" or temperate zone climate. In common with much of the central Ethiopian plateau, the Megech project area has a relatively cool, pleasant climate with a narrow annual range of temperature and a distinctly seasonal pattern of rainfall distribution.

Although there is no weather station in the project area itself, weather records have been kept since 1955 at Bahr Dar, about 60 kilometers south of the project area. These records show that the area has an average daily temperature of around 18.5°C,[1] while the average daily maximum and minimum are 26°C and 10.9°C,[2] respectively. Daily variation in temperature is very limited throughout the year, but the night temperatures show some variation. Night temperatures are usually at their lowest in December.

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[1] Imperial Ethiopian Government, Central Statistical Office, Ethiopia: Statistical Abstract, 1972, p. 12.

[2] Ibid.

The highest daily temperatures occur in March, April or May. Although there could be occasional frosts in October or November, temperatures are ideal for crop production throughout the year.

The long term average annual rainfall for the area is 1,490.9 millimeters,[1] with the highest recorded amount being 1,844.7 millimeters (1971) and the lowest, 1,065.9 millimeters (1965). While this amount of rainfall seems to provide an adequate level of moisture for plant growth and other purposes, its seasonal distribution is highly skewed. The moisture deficit is exacerbated by the high rate of evapotranspiration during the dry season. The net result of the drastic variation in moisture levels is ecologically devastating and it affects the well-being of the human population in every conceivable way.

Generally speaking, the rainy season extends from June to the middle of October, but small rains do occur in April and May. These, however, are usually unreliable for crop production purposes. The remainder of the year has little precipitation. Hence, severe water stress prevails throughout the region between late October and mid-April.

Population

The present population of the Megech Project area is

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[1] Ibid., p. 10.

estimated to be about 6,904,[1] with an approximately fifty-fifty sex ratio. The population is entirely rural, deriving its livelihood from subsistence farming. Living conditions as indicated by the level of food consumption, quality of clothing and shelter are very low and in general quite characteristic of the population of the highland plateau.[2]

Existing Agricultural System

According to the Blue Nile Basin Survey, the land in the project area is heavily utilized during the wet season. It has been estimated that 87 percent of the land is predominantly cultivated cropland while 13 percent is classified as partially cultivated cropland.[3]

The area as a whole is suitable for the cultivation of a wide variety of crops including those adapted to subtropical and temperate zones. The major cultivated crops of the area are teff, barley, sorghum, noog, chick peas, lentils and peppers. There are also some less important

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[1] The population figure is arrived at by adjusting the 1964 population estimate reported in United States Department of Interior, Bureau of Reclamation, Land and Water Resources of the Blue Nile Basin, p. 232, by the annual average national rate of population growth of 2.3 percent for the period 1965 to 1975.

[2] Extensive coverage on living conditions, food habits, customs and traditions of the people of the area is provided by Frederic J. Simoons, Northwest Ethiopia: Peoples and Economy.

[3] United States Department of Interior, Bureau of Reclamation, Land and Water Resources of the Blue Nile Basin, p. 217.

crops such as millet, corn, wheat, sunflowers, guaya, coffee, perennial cotton, and spices of various types.[1]

Farming practices follow the traditional pattern. Crops are generally planted in June and July and harvested in November and December. The cultural practices include seed bed preparation, planting, weeding, harvesting and threshing. A team of oxen constitute the basic unit of power for ploughing. Planting is done by hand broadcasting the seeds, and the broadcast seeds are plowed under or trampled over by livestock in the case of teff. Weeding and harvesting are done by hand, and threshing is accomplished by driving cattle over well spread out stocks of grain on a threshing ground. The grain is separated from the chaff by throwing the threshed grain into the air so that the lighter parts are blown away while the heavier grain falls to the ground. The clean grain is then put into sacks and hauled home on the backs of donkeys. Although grain production is the dominant farm enterprise, the existing agricultural system can be characterized as a mixed system, with livestock supplementing crop production in providing the subsistence requirements of the farm households.

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[1] An excellent discussion on the cultivated crops of the region and the cultural practices followed in their cultivation is presented by Frederic J. Simoons, Northwest Ethiopia: Peoples and Economy.

Markets and Transportation

Because the chief motive for production is to satisfy the subsistence requirements of the family, only a small percentage, probably a quantity not exceeding 15 percent of the annual output, is marketed. The marketable surplus is sold in local markets, usually immediately after harvest. The products are ordinarily transported to local markets by pack animals. All the marketed surplus is then assembled by local merchants and subsequently trucked to the larger market centers, some of which may eventually reach the terminal markets of Addis Ababa and Asmera. The area is accessible both by road and by air. In view of the strong demand for farm commodities in Ethiopia, market outlets for the products of the area do not seem to pose any particular problem.

Megech Project Description

The proposed Megech River Project involves the use of the waters of the Megech River for irrigating 5,890 hectares of land. An integral part of the project is also the provision of clean and safe water supplies for domestic consumption and livestock use. Although livestock enterprises do not form part of the proposed program, it is anticipated that the participants of the project will keep an average of five animal units per household in order to supplement their food supply and possibly obtain petty cash from the sale of the animals. The pro-

ject is intended to provide approximately 53.01 million cubic meters of water per irrigation season, which extends from mid-October to the end of May, 28.11 thousand cubic meters per year for domestic purposes, and 15.72 thousand cubic meters per year for livestock use, or a total of 53.05 million cubic meters of water per year.

The required quantity of water will be withdrawn from the Megech River using a set of electric pumps and will subsequently be distributed for the various purposes through a network of canals, laterals and specialized distribution units. It is intended that power for pumping and other project uses will be obtained from the hydro plant at Bahr Dar. The major structural features of the project include the power transmission line, the pumping plant, canals, laterals and tertiaries, drainage canals, access roads, community water outlets, stock watering spots and a host of community service facilities such as a school, a clinic, a community center, offices and living quarters.

It should, however, be pointed out that although the provision of domestic and stock water supply has been mentioned here as being part of the project primarily to underscore the need for such facilities, the irrigation aspect of the project by far dominates the entire project. For all practical purposes then, what is being considered here is an irrigation project and subsequent analysis rightly recognizes this basic fact.

The project is expected to be phased in over a ten year period. Each year 10 percent of the land will be developed and full scale irrigation as well as full irrigation yields are expected to be achieved at the end of the tenth year. The phasing-in of the project by stages is especially useful because of the need to educate the participating farmers about the techniques of irrigation farming, as well as to plow back profits gained in the initial years. This manner of development also offers the opportunity for making necessary changes in plans or in the operation of the system before large investment costs are incurred. In essence, then, this system of development by stages helps to minimize irreversibilities and maximize flexibility both in construction and operation of the project.

Kesem River Project Area

Location

The Kesem River study area is located on the west bank of the Kesem River in the Middle Awash Valley. The Kesem River itself is one of the major left-bank tributaries of the Awash River. The project is planned to be centered slightly northwest of the point at which the Kesem joins the Awash. More specifically, the center of the project is fixed at 40° 10' east longitude and 9° 20' north latitude. The general elevation of the area is about 800

meters above sea level,[1] and the project encompasses about 5,650 hectares of irrigable land.

Soils, Topography and Climate

The soils of the Kesem Project area are mostly alluvial, with a clay to clay-loam consistency.[2] Experience at the local plantation and Melka Werer experiment station indicate that the soils of the area have a relatively high level of fertility. Furthermore, they are low in salinity, well drained, and very amenable to irrigation agriculture. The area has a relatively flat topography and the natural vegetation consists mainly of widely scattered acacia trees, native grass, bush and scrub. Mean annual rainfall for the Middle Awash Valley is variously estimated at between 450 and 500 millimeters. Most of the rainfall occurs between July and September.[3] The mean annual air temperature is approximately 28°C, but the maximum temperature may go as high as 40°C, while the minimum seldom goes below 20°C.[4]

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[1] Carl F. Miller, *et al.*, *Systems Analysis Methods for Ethiopian Agriculture*, p. 31.

[2] M.E. Quenemoen, *Potential Returns from Commercial Farming Systems in Three Areas of Ethiopia*, p. 40.

[3] Food and Agriculture Organization, *Survey of the Awash River Basin, Volume III: Climatology and Hydrology* p. 21.

[4] Carl F. Miller, *et al.*, *Systems Analysis Methods for Ethiopian Agriculture*, p. 57.

Estimates of relative humidity range from 43 percent in June to 61 percent[1] in August; the mean annual level of humidity is around 50 percent. The average wind speed for the region is approximately 13.5 kilometers per hour. Strong winds seem to prevail during the months of May, June and July.[2] Without irrigation, crop production in this area is highly risky not only because of the generally inadequate and unreliable nature of the rainfall, but also due to the very high rate of evapotranspiration that is characteristic of the area. The mean rate of evapotranspiration for the area is approximately 12.3 millimeters per day.[3] The annual level of evapotranspiration, therefore, by far exceeds the annual level of rainfall, thus creating a moisture deficit in the region.

Population

The Middle Awash Valley is traditionally occupied primarily by nomadic pastoralists. Consequently, the region as a whole is sparsely populated. The population density for the whole middle valley region is estimated at between 9 and 5 persons per square kilometer.[4] While there is no

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[1] Ibid.

[2] Ibid.

[3] Ibid., p. 207.

[4] Mesfin Wolde Mariam, "The Awash Valley: Trends and Prospects," p. 18.

sedentary population in the study area at the present time, the area is nevertheless part of the traditional grazing land of the Adal nomads and hence may be occupied during the grazing season by as many as 282 nomad families.

Existing Agricultural System

As pointed out in the foregoing, the Kesem River Project area is not cultivated at present. It is primarily used for grazing purposes by the nomads during certain periods of the year. Legal ownership of the land rests with the government and the Awash Valley Authority[1] is the controlling public agency.

Although large sections of the land in the Awash Valley, including the area selected for the present project, are yet to be developed, the Middle Awash Valley in particular has been the site of considerable agricultural activity since the mid-1960's. As a result, a number of fairly large commercial farms have been established in the Valley and are now operating successfully. These include irrigated cotton and sugar cane plantations which presently account for a significant proportion of the cultivated land. The region is generally suitable for the cultivation of a wide range of crops under irrigation. The Middle Awash

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[1] The Awash Valley Authority is an autonomous public agency established in 1961 for the purpose of administering the development of the land and water resources of the Awash River Basin.

Valley as a whole is said to have immense potential for large scale irrigated production of such crops as groundnuts, maize, haricot beans, bananas, citrus fruits, graps and papayas.[1]

In sharp contrast with the traditional farming practices of the highlands, farm operations in the Awash Valley are performed by mechanized units, except for such operations as planting, weeding, harvesting, and picking cotton, for which manual labor is normally employed. The farm management practices usually applied in the area include seedbed preparation, planting, cultivation, crop maintenance (application of fertilizer, pesticides and water), harvesting, threshing (or ginning in the case of cotton), and crop residue removal. On most of the commercial farms in the area, irrigation water is drawn directly from the Awash River using diesel pump sets.

Transportation and Markets

The project area can be approached both by rail and highway. Farm products from the area can therefore be trucked or shipped to market by rail. The Awash Valley is centrally and conveniently located to supply most of Ethiopia's major market centers including Addis Ababa, Dire Dawa, Nazreth and Assab. In view of the projected strong demand for farm commodities in Ethiopia, market outlet is

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[1] Food and Agriculture Organization, Survey of the Awash River Basin, Volume I: General Report, p. 12.

not foreseen as a constraint to increasing farm output.

Kesem Project Description

The project proposed for the development of the Kesem River is, in many respects, similar to the Megech River Project. The Kesem Project basically involves the use of the waters of the Kesem River to irrigate approximately 5,650 hectares of land and also to provide water for household and livestock consumption. Unlike the Megech Project, however, the Kesem scheme calls for a new settlement program.

While a significant proportion of the settlers will be relatively experienced farmers who would like to make a new beginning and build a better life, at least 282 of the expected final settlers will be nomadic herders who presently use the area as part of their traditional grazing lands. It is noted that settlement schemes in general have had only mixed success both in Ethiopia and other parts of the world.[1] The successful settlement of nomads is likely to be an even more difficult and complex proposition. It is fully recognized that deeply ingrained, centuries old traditions cannot be discarded easily despite the fact that the future survival of such traditions, in the face of mounting population pressure on the available land, is very doubtful. Since change appears inevitable, particu-

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[1] Yujiro Hayami and Vernon W. Ruttan, Agricultural Development: An International Perspective, p. 282.

larly for the nomads of the Awash Valley, the overriding concern at this point should be how to make the transition relatively smooth and less painful to them. To that effect, the Kesem Project can benefit from the experience gained at other schemes, both at home and abroad.

As presently conceived, the project envisages a gradual and properly coordinated transition from nomadic pastoralism to sedentary farming. The strategy involves two fundamental stages. In the first stage, attention will be directed toward eliminating the need for nomadism by providing adequate water and livestock feed. This can be accomplished through proper development and management of water and range lands. Once the nomads have adjusted to a settled way of life, the second stage of the program will be initiated. The focus in this stage should be on education, motivation and incentives. While a detailed discussion of these factors is clearly outside the scope of the present work, it should be mentioned that the educational program should at least increase their consciousness about their material well-being and provide them with the requisite knowledge and skills that will enable them to adjust to a new way of life. The motivational and incentive programs necessary to develop and maintain interest in crop production naturally should be a continuing feature of project operation.

The physical plan of the Kesem scheme calls for the withdrawal of approximately 84.8 million cubic meters of

water annually from the Kesem River. Literally 99 percent of this water will be used for irrigation. It is anticipated that diesel pump sets will be used to lift the water directly from the river. The basic construction features of the project include access and farm roads, pumping plants, water storage reservoirs, distribution systems, housing for settlers and employees, and a wide range of service facilities. The breakdown of cost estimates of these features is presented in Chapter VII.

The project is planned to be phased in over a ten year period, with approximately 10 percent of the land being developed each year. Such a plan of action is adopted in order to minimize irreversibilities and allow flexibility in both construction and project operation. Furthermore, this plan affords sufficient time to educate the settlers in the practice of irrigation agriculture. It will also allow management to gain from initial experiences and adjust plans accordingly. Therefore, it may reduce the need for outside capital by permitting the reinvestment of net earnings made during the initial years of operation.

Finally, the financial investment required for implementing both of these projects is expected to come from the public sector. Consequently, it is essential to empirically demonstrate that the public interest will be properly served by embarking on the proposed investment program. A valid empirical analysis of public investment must necessarily be based on an appropriate theoretical and

analytical framework. The following chapter describes the analytical approach employed in the present study.

CHAPTER V

ANALYTICAL FRAMEWORK

The estimation and prediction of various economic impacts of water resource investment is a complex process. The literature on the subject is extensive, and over the years a number of quantitative techniques have been demonstrated to be applicable for assessing the impact of water projects. A range of techniques including econometrics, input-output analysis, optimization techniques, benefit-cost analysis and simulation studies have been utilized in analyzing water projects. Each of these techniques has varying data requirements, and experience seems to suggest that no single technique offers a panacea. It is often desirable to use a combination of two or more analytical tools to obtain a more complete and reliable result.

The choice of analytical techniques depends, among other things, on the range and quality of data available and the nature of the problem being considered. For instance, use of the input-output technique would require the availability of an I/O table and an extensive amount of data regarding sectoral commodity flows and detailed inter-industry relationships. In contrast, the data requirement of the benefit-cost analysis technique is some-

what modest but its application will not lead to correct results if the project is so large as to have a considerable impact on output, prices and general economic activity. Programming and simulation techniques also have detailed data requirements and are generally more suited for optimizing resource allocation at the "operating level" of decision making (i.e., households, firms, and industries) rather than at the regional, institutional or policy decision making levels. Further, all these techniques do not necessarily address the same kinds of problems. Benefit-cost analysis has been successfully applied in the economic evaluation of public investment in water projects, particularly in those cases where the projects have no discernible effect on general equilibrium. Considering the available data and the limited size of the projects proposed in this study, benefit-cost analysis does seem to be an appropriate technique for evaluating the overall economic impact of these projects.

However, while benefit-cost analysis is useful in evaluating the overall economic feasibility of an irrigation project, it does not help determine the optimal crop mix or the optimal land allocation plan for the project area. What benefit-cost analysis does is simply evaluate the overall economic impact of a given level of project operation, whether that level of operation is optimal or not. Yet, the type of crop mix assumed can significantly influence the level of projected benefits and costs. In

order to circumvent this weakness, it is necessary to employ other complementary techniques that can help determine the optimal crop mix for the proposed project subject to the available resources and other constraints. Accordingly, a complementary technique of recursive programming was employed to determine the annual optimal crop mix in the present study. The analytical models of this study are, therefore, based on the combined techniques of recursive programming and benefit-cost analysis. In this chapter an attempt will be made to present a concise review of these techniques.

A Review of Recursive Programming

The project areas considered in this study are suitable for the production of a wide variety of crops. The yields of these crops are expected to increase gradually as a result of the irrigation project. Given the objective of production and the resource restraints for each area, economic logic demands that, during each production period, only those crops that can maximize the objective function be produced. An optimization technique is required to determine the optimum annual crop mix over the planning horizon. Accordingly, recursive programming was selected to accomplish the task of determining the optimal annual crop mix and optimal land utilization plan for the areas studied.

Recursive programming[1] is essentially a sequence of linear programming models in which the objective function, the technical coefficients, or the resources constraints of a particular model depend upon the solution variables of the preceeding model in the sequence. Unlike linear programming which attempts to optimize a single period objective function, recursive programming explicitly includes time in its optimization process and as such exhibits a dynamic character. The recursive system is initiated by establishing the activities and constraints for the first year in the manner of an ordinary linear programming model. The values of the variables in the optimal solution are then used in a subsequent matrix and the procedure continues until the entire planning horizon is covered. Since a different linear programming matrix is developed for each time period, annual changes in anticipated yields and resource levels can be easily and adequately incorporated into the model.

The agricultural application of recursive programming has largely been in the area of production response

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[1] For a more comprehensive discussion on recursive programming, see: R.H. Day, Recursive Programming and Production Response (Amsterdam: North Holland Publishing Company, 1963); R.H. Day, "Recursive Programming and Supply Prediction," in Agricultural Supply Functions: Estimating Techniques and Interpretations, edited by Earl O. Heady, et al. (Ames, Iowa: Iowa State University Press, 1958); and R.K. Sahi, "Recursive Programming Analysis of Prairie Land Utilization Pattern" (Unpublished Ph.D. Dissertation, University of Manitoba, Winnipeg, 1972).

studies.[1] In the present study it is employed as a dynamic optimization technique in order to determine the optimum production pattern of project commodities over a specified planning horizon. The basic elements of the recursive programming models used in this study are as follows:

$$\text{Max } Z_t = \sum_{j=1}^{n} P_{jt}X_{jt}, \quad t=1,\ldots,T; \quad j=1,\ldots,n \tag{5.1}$$

subject to the conditions:

$$\begin{aligned}
&a_{11}x_{1t} + a_{12}x_{2t} + \ldots + a_{1n}x_{nt} \leq (1 + \beta_{1t})b_{1t-1} \\
&a_{21}x_{1t} + a_{22}x_{2t} + \ldots + a_{2n}x_{nt} \leq (1 + \beta_{2t})b_{2t-1} \\
&\ldots \quad \ldots \quad \ldots \quad \ldots \quad . \quad \ldots \quad \ldots \\
&a_{m1}x_{1t} + a_{m2}x_{mt} + \ldots + a_{mn}x_{mt} \leq (1 + \beta_{mt})b_{mt-1};
\end{aligned} \tag{5.2}$$

$$(1 + \lambda_{jt})x_{jt-1} \geq x_{jt} \geq (1 - \lambda_{jt})x_{jt}-1;$$

$$x_{jt} \geq 0.$$

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[1] See R.H. Day, "Recursive Programming and Supply Prediction"; J.M. Henderson, "The Utilization of Agricultural Land: Theoretical and Empirical Inquiry," Review of Economics and Statistics, 42 (1959), pp. 242-259.

where: Z_t = the objective function (net farm income) to be maximized in year t,

P_{jt} = the expected net return per unit of commodity j produced in year t,

x_{jt} = the level of the j^{th} commodity produced in year t,

x_{jt-1} = the level of the j^{th} commodity produced in year t-1,

b_{it-1} = the level of resource i used in year t-1, i=1,...,m,

β_{it} = the flexibility coefficient of resource i in year t, t=2,...,T,

λ_{jt} = the flexibility coefficient of commodity j in year t, t=2,...,T,

m = the number of resource restraints,

n = the number of commodities,

a_{ij} = the number of units of resource i required to produce one unit of commodity j in period t. These are the technical coefficients for each commodity,

T = the planning horizon.

The difficult part in developing recursive programming models is the estimation of the commodity and resource flexibility coefficients. Various approaches exist for

estimating these coefficients[1] and each approach has its merits and drawbacks, depending on the problem under consideration and the availability of data. In this study, the resource flexibility coefficients (β_i's) are determined by computing the annual rates at which each resource is projected to expand in order to achieve full development of the project areas in ten years. The commodity flexibility coefficients (λ_j's), which apply to the staple commodities, are designed to reflect the annual growth rates in the consumption requirement of the farm families in the project areas as well as expected changes in the farmers' behaviour in the face of new opportunities. They are therefore extrapolated from the expected rate of population growth in the project areas and the estimated annual growth rates in the expected levels of commodity yields.

The solution to the model involves finding a set of x_{jt}'s that can maximize the objective function (5.1) without violating the restrictions indicated by (5.2). The solution procedure for recursive programming is similar to that of ordinary linear programming. The simplex algorithm familiar in linear programming can be successfully employed in the solution of recursive programming problems. The

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[1] See R.K. Sahi and W.J. Craddock, "Estimation of Flexibility Coefficients for Recursive Programming Models -- Alternative Approaches" (Paper presented at the Joint Annual Meetings of the American Agricultural Economics Association and the Canadian Agricultural Economics Society, Edmonton, August 8-11, 1973).

simplex procedure requires the inclusion of slack variables in the model to change the inequalities in (5.2) to equalities. The resulting system of linear equations is then solved using an iterative procedure that starts with a set of basic feasible solutions and proceeds to the optimal solution set. Once the model is set up, a computer program can be developed to solve the entire sequence of recursive programs in one run. The final solution then provides the optimal annual crop mix and land utilization plan extending over the entire planning horizon.

Recursive programming models share most of the limitations of ordinary linear programming models. First, they are based on the assumption of a linear production function. However, there is no reason why non-linear recursive models may not be specified if they are more likely to properly represent the underlying production function. Second, the production processes are assumed to be infinitely divisible, whereas in reality this may not always be practicable. Third, it is assumed that the inequations in the model are linearly independent or that the technology matrix (A) has a non-zero determinant. Unlike the ordinary linear programming models, however, the recursive model can be expected to provide positive solutions because the decision-makers expected behavior can be more readily incorporated into

the model through the medium of flexibility constraints.[1]

A Review of Benefit-Cost Analysis

As a tool for evaluating public investment projects, benefit-cost analysis has a fairly long history. Its origin has been traced back to the noted nineteenth century French economist, Dupuit,[2] who incorporated the idea in his classical paper "On the Measurement of the Utility of Public Works,"[3] published in 1844. In the present century benefit-cost analysis has gained popularity as a practical administrative tool used in evaluating federal water resource projects in the United States.[4]

Theoretical economists initially were indifferent

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[1] W.J. Craddock, "Linear Programming Models for Determining Irrigation Demand for Water," Canadian Journal of Agricultural Economics, Vol. 19 (November, 1971), pp. 84-92.

[2] A.R. Prest and R. Turvey, "Cost-Benefit Analysis: A Survey," Economic Journal (December, 1965), pp. 683-731, reprinted in Surveys of Economic Theory Prepared for the American Economic Association and the Royal Economic Society, Vol. 3 (London: Macmillan, 1966), pp. 155-207.

[3] Jules Depuit, "On the Measurement of the Utility of Public Works," translated by R.H. Barback in International Economic Papers, 2 (1952), pp. 83-110, reprinted in K.H. Arrow and T. Scitovsky, eds., Readings in Welfare Economics (Homewood, Illinois: Richard D. Irwin, Inc., 1969), pp. 255-283.

[4] For a history and development of benefit-cost analysis in the U.S., see: R.J. Hammong, Benefit-Cost Analysis and Water Pollution Control (Stanford, California: University Press, 1958).

to or rejected benefit-cost analysis because they considered it to lack a sound theoretical base. Interest in the subject, however, has steadily grown and professional literature on the subject is proliferating. Numerous books and journal articles have been published since Otto Eckstein's path breaking work in this field first appeared in 1958.[1]

Interest in the subject of benefit-cost analysis has continuously increased in Canada and the United States as well as in other countries, notably the United Kingdom, France and Germany. The relevance of the technique to public investment planning in less developed countries has

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[1] Otto Eckstein, Water Resource Development: The Economics of Project Evaluation (Cambridge, Massachusetts: Harvard University Press, 1958).

Among the important literature on benefit-cost analysis are: S.C. Ciriacy-Wantrup, "Benefit-Cost Analysis and Public Resource Development," in S.C. Smith and E.N. Castle (eds.), Economics and Public Policy in Water Resource Development (Ames, Iowa: Iowa State University Press, 1964), pp. 9-21; Ajit K. Dasgupta and D.W. Pearce, Cost-Benefit Analysis: Theory and Practice (London: Macmillan, 1972); R. Dorfman (ed.), Measuring Benefits of Government Investments (Washington, D.C.: Brookings Institution, 1965); C.D. Foster, "Social Welfare Functions in Cost-Benefit Analysis," in J. Lawrence (ed.), Operational Research and the Social Sciences (London: Tavistock Publications, 1966); A. Maass (ed.), Design of Water Resource Systems (New York: Macmillan, 1962); R. McKean, Efficiency in Government Through Systems Analysis (New York: John Wiley, 1958); E.J. Mishan, Cost-Benefit Analysis (London: George Allen and Unwin Ltd., 1971); and A.R. Prest and R. Turvey, "Cost-Benefit Analysis: A Survey."

been recently demonstrated by a number of authors.[1] International organizations such as the United Nations, the Organization for Economic Cooperation and Development and the International Bank for Reconstruction and Development have published project evaluation manuals based on the benefit-cost analysis approach for use in developing countries.

While critiques of benefit-cost analysis have not been lacking,[2] it is becoming more apparent that the handicaps and deficiencies inherent in this technique are also shared to some extent by other quantitative techniques in economics. Benefit-cost analysis, like all other tools of applied economics, no doubt needs a great deal of improvement and refinement. But it must be emphasized that if applied with caution and prudence, benefit-cost analysis can be an extremely useful tool of social investment analysis.

The fundamental aim of benefit-cost analysis is to identify the pertinent and significant social costs and

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[1] See, for instance, J. Price Gittinger, Economic Analysis for Agricultural Projects (Baltimore: The Johns Hopkins University Press, 1972); S.A. Marglin, Public Investment Criteria (London: George Allen and Unwin, 1966); and I.M.D. Little and J. Mirrlees, Manual of Industrial Project Analysis in Developing Countries, Vol. 2: Social Cost-Benefit Analysis (Paris: O.E.C.D., 1969).

[2] For a survey of critiques of benefit-cost analysis see: L.D. James and Robert R. Lee, Economics of Water Resource Planning (New York: McGraw-Hill Book Company, 1971), pp. 191-192.

social benefits associated with public projects, assess their true value to society and rank them according to some order of social preference. Benefit-cost analysis, therefore, is a quantitative technique useful for making economic choices at the social level.

A discussion of the many reasons why public investment appraisal ought to be different from private investment analysis is beyond the scope of this study. But it seems essential to mention at least three fundamental concepts that distinguish social investment analysis from private investment analysis within the context of a mixed economy.

First, in principle, social investments are made in public goods and services such as national defence, education, health, public parks and flood control. These goods and services are in general characterized by indivisibility in construction and inappropriability in use. Furthermore, once the investment is made, the marginal cost of making an additional unit available to consumers, up to the point of "congestion", is zero. Hence, ordinary market mechanisms do not exist or are inadequate to establish socially acceptable prices for such public goods and services.

Second, social investments are also made in goods and services whose market prices, where they do exist, do not reflect the appropriate social value of the goods to society due to market imperfections. Unique resources and

public utilities belong to this category of goods.

Third, social and private costs diverge widely in enterprises and sectors where there are significant and widespread external economies and diseconomies. For instance, agricultural research and water development belong to this category of enterprise. The externalities generated in these sectors cannot be sufficiently internalized by the producing units through the market system. In the presence of externalities, therefore, market prices fail to reflect the true social values of goods and services.

To recapitulate, the public good characteristics of certain categories of goods and services, the existence of market imperfections and the presence of externalities, among other things, make the use of an analytical approach which is broader than the strict application of capital theory imperative for public investment evaluation. Although benefit-cost analysis attempts to provide a broader and wider framework for public investment appraisal, it will be shown below that the situations mentioned above create serious problems in benefit-cost analysis as well.

In public project evaluation, benefit-cost analysis may be used for three broad purposes:[1]

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[1] S.V. Ciriacy-Wantrup, "Benefit-Cost Analysis and Public Resource Development," in Stephen C. Smith and Emery N. Castle (eds.), <u>Economics and Public Policy in Water Resource Development</u>, p. 14.

1. To appraise the economic feasibility of a set of public projects and determine their relative rankings.
2. To determine the financial feasibility, cost allocation, and cost repayment of public projects.
3. To determine the pricing procedure for those products of the public project that may be sold to users or consumers.

The present study deals with the evaluation of economic and financial feasibility of alternative public projects designed to serve a specific purpose. Consequently, the following discussion on the elements of benefit-cost analysis follows this vein.

Within the framework of benefit-cost analysis, it is essential to make distinctions between economic feasibility analysis and financial feasibility analysis. Economic feasibility analysis seeks to determine the social profitability of a project by taking into account all the relevant market and extra-market benefits and costs of a particular project. Its basic aim is to establish the economic efficiency of the project or projects under consideration and thereby help select the "best project" or rank the projects involved on the basis of some criteria of social preference.

Although economic feasibility analysis does indicate whether or not a particular project is socially desirable, it does not necessarily follow that an economically feasible

project will also be financially feasible. More specifically, an economically feasible project may fail to be financially feasible because sufficient revenue may not be collected to cover the annual operating and amortized costs of the project. Economic logic and practical experience also tend to indicate that various methods of project financing and cost repayment arrangements can have different impacts on both the financial feasibility of the project and the distribution of income among the various groups likely to be affected by the proposed project. The purpose of financial analysis, therefore, is to examine the implications of the various methods of project financing, cost repayment and output pricing. Each of these areas of benefit-cost analysis will be investigated in some detail below.

Economic Analysis

The appraisal and ranking of public projects according to a specific order of social preference represent the main concerns of economic analysis. The essence of economic analysis, then, is the assessment of the social benefits and costs of proposed projects in order to determine both their internal efficiency and their relative economic merit vis-a-vis the rest of the economy. Economic analysis is composed of the following basic elements: (a) determination of project selection and ranking criteria; (b) estimation of the future stream of benefits; (c) estima-

tion of costs; (d) choice of the social discount rate; (e) specification of the planning horizon; (f) evaluation of risk and uncertainty; (g) sensitivity analysis; and (h) comparison of project area economic performance "with" and "without" the proposed project.

A. Public Project Selection and Ranking Criteria

The primary purpose of public project evaluation, of course, is to determine whether the social benefits accruing from the project will outweigh the social costs of the project. An important aspect of public project evaluation is to compare and rank alternative projects that can help maximize a social objective subject to the relevant constraints. To successfully accomplish either or both of these tasks, it is necessary to adopt logical and consistent decision rules. At least three types of investment criteria appear to have relevance to public investment evaluation. They include (1) the net present discounted value; (2) the internal rate of return; and (3) the benefit-cost ratio.

1. The Net Present Discounted Value Criterion

The net present discounted value criterion, as the name implies, involves the discounting of all future streams of benefits and costs over the economic life of the project to the present using an appropriate discount rate and then deriving the net present value by subtract-

ing the sum of the present value of costs from the sum of the present value of benefits. Alternatively, the same result can be obtained by subtracting annual costs from the corresponding annual benefits and then summing the discounted net value over the economic life of the project. A more concise algebraic definition would appear as:

$$PV(r) = \sum_{t=0}^{T} \frac{B_t - (C_t + K_t)}{(1 + r)^t} \quad \text{for discrete time periods,}$$

$$PV(r) = \int_0^T (B_t - (C_t + K_t))e^{-rt}\, d_t \quad \text{for continuous time periods.}$$

where $PV(r)$ = the net present value discounted at the rate (r),

B_t = gross benefits at period t,

C_t = associated costs at time t,

K_t = project costs at time t,

r = the social discount rate assumed to be constant over the planning horizon,

T = the planning horizon.

The decision rule, then, is to rank projects according to the magnitude of the positive net present value, with projects showing $PV(r) < 0$ being rejected.

Although very useful in determining the social desir-

ability of a particular project, the net present value criterion has been found wanting as a decision rule for ranking alternative projects. Empirical investigation has shown that the net present value criterion will, under certain conditions, lead to inconsistent ranking of projects. Mishan,[1] for instance, has shown that for two non-dominant projects, the net present discounted value gives inconsistent ranking over different ranges of the discount rate if their capital requirements, their economic life spans and the profile of the time-streams of their benefits and costs are significantly different from each other. Such inconsistencies have also been noted by P.C. Van den Noort.[2]

In a major theoretical work on public investment, Marglin[3] has shown the inappropriateness of using the net present value criterion as a decision rule. He has illustrated how the failure of the "static" present value criterion to incorporate calendar time and project age in the analysis leads to inaccurate ranking and an improper timing of projects. This criterion also tends to favor

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[1] E.J. Mishan, Cost-Benefit Analysis, p. 193.

[2] P.C. Van den Noort, "Investment Criteria for Government Projects," Landbowukundig Tijdschrift, Vol. 75, No. 9 (September, 1966), pp. 306-311.

[3] Stephen A. Marglin, Approaches to Dynamic Investment Planning (Amsterdam: North-Holland Publishing Company, 1963).

large projects over small.[1]

The fact that the present value criterion involves the prior determination of a discount rate and that the criterion itself fails to always lead to a consistent and appropriate ranking caused interest to shift to the internal rate of return as a decision criterion. Since each project has its own internal rate of return that can be determined through objective calculation, it seemed to provide an attractive alternative to the present value criterion. But the internal rate of return is not entirely free of criticism either.

2. The Internal Rate of Return Criterion

The internal rate of return is defined as that rate of return which makes the present value of benefits exactly equal to the present value of costs. In a concise mathematical form:

$$\sum_{t=0}^{T} \frac{B_t - (C_t + K_t)}{(1 + \lambda)^t} = 0 \quad \text{for discontinuous time perior, or}$$

$$\int_0^T (B_t - (C_t + K_t))e^{-\lambda t}\, d_t = 0 \quad \text{for continuous time period.}$$

[1] Otto Eckstein, Water Resource Development: The Economics of Project Evaluation, p. 53.

where λ = the initial rate of return and the other variables are as defined on page 129. According to the internal rate of return criterion, projects that show λ values greater than the exogenously determined opportunity rate of return to social capital, are accepted and these are ranked in a descending order of their λ values.

The internal rate of return criterion, like the present value criterion, has been subject to several criticisms. It has been demonstrated that more than a single internal rate of return may correspond to a given benefit stream that lasts over two periods.[1] Hirschleifer[2] has further shown that, except under very peculiar circumstances, the internal rate of return criterion will lead to non-optimal results as long as the capital market is not perfectly competitive.

While many more criticisms may be cited. it seems clear that both the present value and the internal rate of return have shortcomings as decision criteria for public investment and they also give inconsistent rankings. Attempts have been made to normalize these criteria so that they will at least give consistent rankings. The most interesting of these attempts is a normalization procedure

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[1] E.J. Mishan, Cost-Benefit Analysis, p. 23.

[2] J. Hirschleifer, "On the Theory of Optimal Investment Decision," Journal of Political Economy (August, 1958), pp. 329-352.

suggested by Mishan.[1] The procedure has four basic elements:

1. All benefits and outlays of any investment stream are to be compounded forward to yield a terminal value TV at some future date.
2. A common capital outlay should be established for all the investment projects being considered.
3. Maximum reinvestment potential for the benefits of each investment stream should be calculated and utilized.
4. The same planning horizon should be used for all projects.

According to Mishan, if these rules are applied, both the internal rate of return calculated for each of the terminal values and the net present discounted value criterion will provide consistent ranking of projects. While this procedure appears to be complex and cumbersome in practice, it seems to imply that both net present value and the internal rate of return are most likely to give consistent ranking if the alterative projects being considered do not significantly differ from each other in terms of their capital requirement, reinvestment opportunity and economic life span. From this standpoint, it provides a very practical guide for public project evalua-

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[1] E.J. Mishan, "A Normalization Procedure for Public Investment Criteria," Economic Journal (December, 1967), pp. 777-796.

tion.

3. The Benefit-Cost Ratio Criterion

The benefit-cost ratio criterion ranks projects according to the ratio of benefits to costs. The benefit-cost ratios may be calculated on either gross or net basis, but it is essential to be consistent in using one or the other formula when ranking projects. The ratio of gross benefits to total costs is calculated by dividing total direct benefits by total (i.e., associated plus project) costs, as illustrated below.

$$G = \frac{\sum_{t=0}^{T} \frac{B_t}{(1 + r)^t}}{\sum_{t=0}^{T} \frac{(K_t + C_t)}{(1 + r)^t}}$$

where G = the gross benefit-cost ratio,

B_t = the gross direct benefit at period t, t=0,...,T,

K_t = project cost, including capital operation, maintenance and replacement cost at period t, t=0,...,T,

C_t = associated cost at period t, t=0,...,T,

r = the social discount rate,

T = planning horizon.

The net benefit-cost ratio, on the other hand, is calculated by dividing the net benefits (i.e., gross benefits minus associated costs) by project costs, as shown below.

$$N = \frac{\sum_{t=0}^{T} \frac{(B_t - C_t)}{(1 + r)^t}}{\sum_{t=0}^{T} \frac{K_t}{(1 + r)^t}}$$

where N = the net benefit-cost ratio and the other variables are as defined above.

According to the benefit-cost ratio criterion, a project is considered economically feasible if its benefit-cost ratio is greater than unity. Alternative projects are then ranked in a descending order of the values of the ratios obtained. While this criterion has proven to be a useful criterion for determining the economic feasibility of a project, it has been found to lead to incorrect ranking of mutually exclusive projects in cases where the capital requirements for each project are significantly different.[1] It has also been found wanting in choosing the optimum scale of investment of a particular project,[2] as

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[1] J. Hirshleifer, James C. De Haven and J.W. Milliman, Water Supply: Economics, Technology, and Policy (Chicago: The University of Chicago Press, 1960), p. 137.

[2] Ibid.

the scale at which the benefit-cost ratio is the highest does not necessarily represent the net benefit maximizing scale of investment. Nevertheless, the benefit-cost ratio criterion can be safely and usefully applied in the evaluation and ranking of projects where the economic nature of the benefits and costs are reasonably uniform and have roughly equal degrees of uncertainty; where the capital intensities of the projects do not show extreme variations; and where the economic life span of the alternative projects is equal.[1]

B. Estimation of Benefits

The proper identification and estimation of benefits and costs form the crux of benefit-cost analysis. Ordinarily, several factors complicate the process of estimating the social benefits and costs of a public project. On the benefit side, a public project usually yields both physical products and non-physical products (or services). The benefits of a particular project therefore depend on the quantity of the output produced and the price at which each unit of the output can be sold. While some socially acceptable prices for outputs are easily obtained, it is often exceptionally difficult to arrive at widely acceptable monetary values for both tangible and intangible out-

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[1] Otto Eckstein, Water Resource Development: The Economics of Project Evaluation, p. 55.

puts. Society, nevertheless, derives satisfaction from both types of output; hence it is essential that both should be properly recognized in project evaluation. Conventionally, three major categories of benefits are recognized in benefit-cost analysis. They include (a) direct benefits; (b) indirect benefits; and (c) extra-market benefits.

1. Direct Benefits

Direct benefits are the socially appropriate market values of goods and services produced directly by a project. For the projects evnisaged in this study, the annual direct benefits include the value of the crops and services produced by the project during a given year. The stream of future direct benefits of the project being considered therefore depend on the expected level of yields and the expected level of prices.

While adequate indications of yield levels may be obtained from past farm records and yield trial results, determination of appropriate commodity prices is a very difficult and complex process. Readily available market prices in general do not reflect the true "social valuation" of the outputs produced and the inputs used in the production process. Only under very rigid assumptions will ordinary market prices serve as correct indicators of true social values. These assumptions include (1) pure competition; (2) full employment; (3) absence of externalities;

(4) small-scale project relative to the economy; (5) absence of indirect taxes, controls, and subsidies; and (6) a constant or increasing cost firm. If any of these assumptions are violated, the market price will fail to reflect the correct social valuation of goods and services.[1]

If, however, there is sufficient reason to believe that the above conditions do hold in the economy being considered, the social benefits and costs can be measured by directly using market prices. But even here certain problems are bound to arise. In general, market prices in different locations behave differently, although in the economy as a whole they are determined competitively. Smaller local markets tend to be less competitive than major terminal markets. Therefore, the price prevailing at the nearest local market may not always be a good representative price for the market as a whole. The common sense solution to this problem is to survey all potential sources of supply and base the evaluation on the market price that seems to be reasonably competitive.

Seasonal price fluctuations can also present a problem, particularly when evaluating agricultural projects. The question of which season's prices to use in the face of considerable seasonal price fluctuation poses a particularly difficult problem in Ethiopia. Commodity price

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[1] Ibid., pp. 690-695. Also see, A.K. Dasgupta and D.W. Pearce, Cost-Benefit Analysis: Theory and Practice, pp. 105-109.

studies in Ethiopia indicate that farm prices undergo rather pronounced seasonal fluctuations.[1] Immediate post-harvest prices are very low while pre-harvest prices are extremely high. The choice of a representative price level, therefore, presents a problem. The most direct approach, of course, is to use the annual average price. But in the presence of extreme values, the average is not a "good" measure of central tendency. The median value could perhaps be a better representative value. Some writers[2] suggest that the most conservative value of immediate post-harvest farm gate prices should be used.

The final area of concern when using market prices in project evaluation is inflation. In this connection it is essential to make a distinction between future increases in the general price level and changes in relative price levels. As long as relative price levels remain unaffected, that is, if the prices of all commodities increase in the same proportion, inflation does not affect the outcome of project evaluation. Hence, base year prices can be used to measure benefits and costs. If, however, one has reason to expect that inflation will have a differing impact on output or input, then each of the items can be inflated by the corresponding expected rate of inflation. Generally

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[1] Alan R. Theody, Marketing of Grains and Pulses in Ethiopia, p. 231.

[2] J. Price Gittinger, Economic Analysis of Agricultural Projects, p. 34.

speaking, there seems to be very little reason to expect inflation to have long term differential impact on prices. Short term lags in some prices may be evident but these will tend to adjust over a period of time. Therefore, it can be safely assumed that changes in the prices of inputs and outputs arising from general inflation will have offsetting effects on costs and benefits. Consequently, using base year prices can provide valid benefit-cost comparisons. It must also be pointed out that using base year prices to value future goods and services is equivalent to deflating future prices to base year levels, which will provide a comparison of real benefits and real costs rather than changes in the monetary value of the goods and services involved.

As stated earlier, use of the market price for valuation of the social benefits and costs of a project is valid only if all the conditions specified above are satisfied. If any of the conditions fail to hold, the market price will fail to provide a "true" measure of social values for the goods involved and hence should be adjusted accordingly. The question of how market prices should be adjusted to reflect social valuation of goods along with the problem of how to derive values for goods and services that do not normally have any market or monetary value form the great issues of benefit-cost analysis. Although not yet widely accepted, various approaches have been developed to circumvent these problems.

When market mechanisms fail to provide the correct social valuation, "accounting" or "shadow prices" are usually employed to determine the social valuation of goods and services. The logic underlying the concept of accounting prices is based on the reasoning that if market prices do not adequately reflect the true intensities of society's preferences for specified goods and services, there should be alternative methods of estimating these intensities.

The particular method used for determining a given "shadow price" depends on the prevailing market condition or, alternatively, on the cause and nature of the market imperfection. Ordinarily, "shadow prices" can be derived for factor inputs through the use of programming techniques. Marginal cost pricing is also a familiar form of "shadow pricing". In cases where the market price includes indirect taxes or subsidies, it can be adjusted accordingly to obtain the "shadow price". If widespread labor unemployment prevails in the economy, the "shadow price" of labor can be set equal to zero, indicating that society will not sacrifice any goods and services if hitherto unemployed workers are put to work on the project. For internationally traded goods, the world price (appropriately adjusted for insurance and transport charges) has been suggested as an adequate "shadow price".[1] Likewise, appropriate adjust-

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[1] I.M.D. Little and J.A. Mirrlees, Manual of Industrial Project Analysis in Developing Countries, Vol. 2: Social Cost-Benefit Analysis, pp. 103-120.

ments can be made to correct for externalities, and other market imperfections. It should, however, be stressed that the use of "shadow prices" or, rather, the method of their determination, is one of the most controversial issues in benefit-cost analysis, primarily because the subjective judgment of the analyst becomes unavoidable in the derivation of "shadow prices".

2. Indirect (or Secondary) Benefits

Indirect benefits include value added to activities influenced by the project through economic linkages (Fig. 5.1), and are ordinarily classified as benefits "stemming from" or "induced by" the project. Indirect benefits stemming from the project result from forward production linkages and are represented by the increase in net income of those who process and market the project output. On the other hand, indirect benefits induced by the project result from backward production linkages and are represented by an increase in the net income of those who provide goods and services to the project.

If pure competition and full employment prevail in the economy, the increase in the net profits of processing and supply firms that can be attributed to the project will be zero and hence indirect benefits will disappear.[1] Even

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[1] A.R. Prest and R. Turvey, "Cost-Benefit Analysis: A Survey," Economic Journal (December, 1965), p. 690.

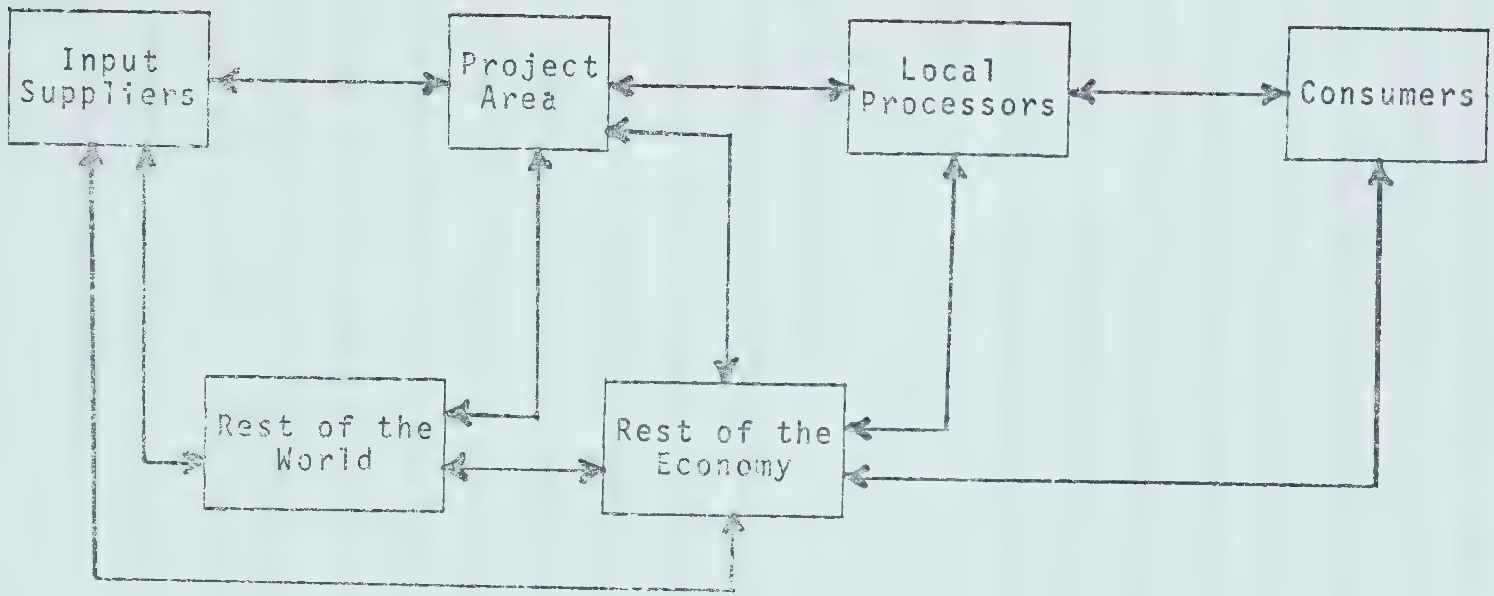

FIGURE 5.1

A MODEL OF FORWARD AND BACKWARD LINKAGES AND GENERAL ECONOMIC INTERDEPENDENCE

in the presence of unemployment, indirect benefits are not considered relevant for purposes of project selection because either indirect costs are assumed to equal indirect benefits, or the net indirect benefits are assumed to be proportionately related to the net direct benefits for the alternative projects being considered.[1] However, indirect benefits can be considered for repayment purposes if it is decided that all project beneficiaries should participate in repayment of the project investment. Indirect benefits are generally considered to be net of indirect costs.

3. Extramarket Benefits

Extramarket benefits involve the values of goods and services that do not normally pass through the marketing system. They include such items as "collective goods" and various types of esthetic, scenic and other social benefits normally called "intangible benefits". Generally speaking, no market mechanisms exist for measuring the monetary value of these goods to society as a whole. It is, however, widely accepted that society does derive real utility from such goods and services. The main difficulty then is how to put monetary value on the benefits that society derives from such goods and services.

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[1] S.V. Ciriacy-Wantrup, "Benefit-Cost Analysis and Public Resource Development," Journal of Farm Economics, 37 (1955), pp. 676-689.

Although the theoretical issues involved in the determination of monetary values for extramarket goods are very complex and remain largely unresolved, certain practical methods have been devised to circumvent the problem. The major approaches to the valuation of extramarket goods have to a large extent been based on deriving simulated market prices.[1] The "willingness to pay" method[2] that has become increasingly popular in evaluating recreation benefits is one such approach. This method is an indirect method of estimating recreation benefits. Travel costs and travel time are used as surrogates to the recreational facility users' "willingness to pay" and the total social benefit of the facility is then obtained by multiplying the individual's "willingness to pay" by the estimated number of visitors per unit of time.

The alternative cost method is another technique of simulating a market value for extramarket goods. This method attempts to infer the value of a non-marketed good from the market price of an alternative product of compar-

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[1] Charles W. Howe, Benefit-Cost Analysis for Water System Planning (Baltimore: Publication Press, Inc., 1971), pp. 47-50.

[2] For a description of the "willingness to pay" method, see M. Clawson and J.L. Knetsch, Economics of Outdoor Recreation (Baltimore: The Johns Hopkins Press, 1966). A further extension of the "willingness to pay" method is presented in F.J. Cesario and J.L. Knetsch, "Time Bias in Recreation Benefit Estimates," Water Resources Research, Vol. 6, No. 3 (1970), pp. 700-704.

able quality. Closely associated with the alternative cost approach is the opportunity cost approach. This latter approach refers to the concept of valuing extra-market goods by assigning them the value of the goods or services sacrificed when scarce resources were diverted to the production of the new goods.

The use of marginal cost pricing to value extramarket goods is another approach that seems to have some adherents.[1] Another perhaps more popular method of valuing non-marketed goods from the standpoint of developing countries is the derivation of imputed prices. This method seems to be particularly useful in pricing non-marketed factor inputs such as labor and land provided that market values exist for the final products.

Finally, it must be emphasized that while the benefits of a great many extramarket goods and services need to be carefully measured in monetary terms, to try to assign money values to all kinds of intangibles for which realistic and meaningful values cannot be derived can make the entire analysis suspect. However, all the possible benefits and costs should be enumerated. Although their worth to society cannot be fully assessed by using economic criteria alone. The subjective values of the public decision-maker become an inevitable ingredient of the

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[1] J. Hirshleifer, James C. De Haven and J.W. Milliman, Water Supply: Economics, Technology and Policy, p. 89.

evaluation process and this should be duly recognized.

C. Estimation of Costs

The costs of a given public project are the sum total of the social values of the goods and services sacrificed in producing the final output of the project. Three major categories of costs are considered relevant to public project evaluation. They include (1) direct costs; (2) indirect costs; and (3) extramarket costs.

1. Direct Costs

Direct costs are costs incurred in producing the direct output of the project. Direct costs have two major components, project costs and associated costs.

Project costs include the values of goods and services used in constructing, operating, maintaining and replacing the various components of the project. In water development, project costs would include the cost of installing and operating storage facilities, conveyance systems and drainage and disposal facilities. Project costs also include the construction costs of access roads and social service centers as well as housing for participants and employees where these are essential for the particular project. These costs have different time profiles. While the investment or installation cost is incurred during the initial period, the operating, maintenance and replacement costs are annual costs that continue over the economic life

of the project.

Associated costs, as distinguished from project costs, are the values of the goods and services necessary to bring forth the direct products and services of the project and to make them available for sale or use. In the case of irrigation, these include the additional costs of land preparation, crop planting, harvesting and marketing the project output.

2. Indirect Costs

Indirect costs comprise the values of the goods and services used to produce the indirect benefits. They encompass all the costs incurred by secondary firms in supplying the project inputs and in transporting, processing and marketing the project outputs. These costs are subtracted from indirect benefits to obtain the net indirect benefits.

The problems and issues previously raised in relation to estimating direct and indirect benefits also apply to the estimation of direct and indirect costs. Since the same approaches suggested for estimating direct and indirect benefits apply here, they have not been repeated.

3. Extramarket Costs

Experience indicates that most projects generate costs or adverse effects which are not properly accounted for through the market. These costs normally include non-

monetary costs imposed on the participants in the project such as the disruption of social life and the spread of environmental health hazards, as well as the price-uncompensated external diseconomies imposed on other producing or consuming units. The latter types of costs primarily include various external costs induced by the project on other firms and industries with which the project is interdependent. More specifically, externalities refer to the uncompensated effects, whether economies or diseconomies, that a new public project produces on the activities of other projects, firms or consumers in the economy.

Dasgupta and Pearce[1] identify two necessary and sufficient conditions for an externality to exist. These are designated as the interdependence condition and the non-price condition. The interdependence condition is satisfied when the economic activity of a project affects the production or utility levels of other producers or consumers. The nature of the interdependence could be producer-producer, producer-consumer, consumer-producer or consumer-consumer. The non-price condition, on the other hand, requires that the effect should neither be priced nor compensated. Both of these conditions must hold for a genuine externality to exist.

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[1] A.K. Dasgupta and D.W. Pearce, Cost-Benefit Analysis: Theory and Practice, p. 118.

While externalities can take several different forms, two general types of externalities may be distinguished.[1]

1. Technological externalities: These refer to project spillovers that affect the input-output relationships of the other producers or the utility functions of consumers. Technological externalities, therefore, either impair or enhance the productive efficiency of the affected firms and the level of satisfaction of the affected consumers. A typical technological externality in irrigation projects, for instance, occurs when the salt-contaminated return flow from upstream fields reduces the productivity of irrigated fields located downstream. Water and air pollution in general is also a good example of technological externality both in production and consumption.

2. Pecuniary externalities: These are externalities that refer to the effect a project will have on the market demand and supply relationship of certain goods and services. They are, therefore, associated with project-induced price changes that affect the benefits and costs of other economic agents. For instance, a new project may increase the demand for some scarce factors of production and consequently increase the price to all purchasers of those factors. The increase in project output may reduce its own price and hence cause the demand for substitutes

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[1] R.N. McKean, Efficiency in Government Through Systems Analysis, pp. 134-150.

to decline or cause the demand for complementary goods to rise. Such changes, of course, benefit either sellers or buyers but always lead to a transfer of income from one party to another.

Pecuniary externalities that merely transfer income from one section of the community to another are not relevant to benefit-cost analysis and hence should not be included.[1] To include them would result in double counting. The purpose of project evaluation is to measure incremental output or income, not a mere transfer of income from one party to another. However, in the case of unemployment or underemployment, the wage payments received by previously unemployed workers represents an increment to national income and hence should be included as a non-technological external benefit to the project. In contrast to pecuniary externalities, technological externalities involve real gains or losses and consequently should be considered in benefit-cost appraisal.

It should be pointed out that technological externalities are in reality a reflection of either the indefiniteness of property rights, the existence of "common property", or the lack of adequate enforcement of property rights. With a clear and complete definition of property rights, it should be possible to eliminate or minimize

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[1] A.K. Dasgupta and D.W. Pearce, Cost-Benefit Analysis: Theory and Practice, p. 121.

technological externalities.

D. The Social Discount Rate

Use of either the net present discounted value or the benefit-cost ratio criterion for project selection and ranking requires prior specification of a social discount rate. Unless the bold assumption of the non-existence of time preference on the part of society is made, a discount rate will be necessary in order to reduce benefits and costs occurring at different points in time to a comparable time period. Likewise, for comparative purposes, use of the internal rate of return also requires prior specification of the social opportunity rate of return.

The choice of an appropriate social discount rate, however, poses a very serious difficulty in public project evaluation. If perfect competition prevailed in both the factor and product markets and there was no divergence between social and private costs, and their respective time preferences, the equilibrium market rate of interest could serve as both the private and social discount rate.[1] But since the real world is characterized by market imperfections, divergence between social and private benefits and costs, and differences between social and private time preferences, the market rate cannot be taken to represent

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[1] Kenneth J. Arrow and Mordecai Kurz, Public Investment, The Rate of Return and Optimal Fiscal Policy (Baltimore: The Johns Hopkins Press, 1970), p. 5.

the social discount rate. The difficulty is further complicated by the existence of many diverse interest rates in the market.

The choice of a particular discount rate, of course, has a direct bearing on project selection. If too high a discount rate is chosen, a potentially profitable project may be rejected, and if the discount rate is too low, projects with unacceptably low returns may be undertaken. The determination of an optimum social discount rate, therefore, is of vital importance in project evaluation.

At present, there is no concensus among economists on how to derive the social discount rate. There seems to be three different schools of thought on the subject.[1] The first argument is based on the notion that the social rate of time preference, as opposed to the private rate of time preference, should reflect not only the preferences of the current generation but also the preferences of future generations. It is often argued that the government is a trustee for unborn generations and that unlike the individual, the society as an entity lives forever. Hence the social discount rate should be lower than the private discount rate which is said to be guided by "myopia" or short-sighted self-interest.

The second school of thought argues that the social

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[1] D.W. Pearce, Cost-Benefit Analysis (London: The Macmillan Press Ltd., 1971), pp. 40-49.

discount rate should reflect the opportunity rate of interest, usually assumed to be in the private sector, on the grounds that failing to do so will result in less profitable public projects displacing more profitable projects in the private sector. To avoid such a misallocation of resources it is suggested that the social discount rate should be equal to the rate of return on marginal projects in the private sector.

The third school of thought argues that, since society has an interest both in the long term social viability and in the short term efficiency of resource allocation, the social discount rate should reflect both influences. In particular, it suggests that a "planner's rate" which takes into consideration both the social and private rates of time preference should be used as a social discount rate. In any event, whichever school of thought is followed, it seems to be difficult to divorce the subjective judgment of the planner in the determination of the social discount rate. Once this is recognized, however, it is essential, from the standpoint of practical project evaluation, to state clearly how the discount rate was arrived at and indicate how sensitive the objective function is to the discount rate.

In Ethiopia the capital market is not well developed as yet. The single most important source of long term capital is the Agro-Industrial Bank of Ethiopia. It is a publicly owned institution whose main purpose is to foster,

promote, and finance agricultural and industrial projects. The interest rates charged by this bank can, therefore, be assumed to represent the social opportunity cost of long term capital in Ethiopia. The bank presently charges different rates for different forms of loans. Agricultural loans are charged interest at the rate of 10 percent while non-agricultural loans are charged at 12 percent or over. In view of the dearth of capital in Ethiopia, it seems that a case can be made for using the interest rate charged by the Agro-Industrial Bank of Ethiopia as the appropriate social discount rate for agricultural projects.

E. The Planning Horizon

The time period over which the economic analysis of a project can be conducted is normally determined by the economic life of the project. The economic life, of course, cannot be longer than its physical life. However, project economic life is greatly influenced by changes in technology and future demand and supply conditions of both inputs and outputs. In a world of perfect foresight, where these changes can be accurately predicted, economic returns can be maximized if the economic life of the project is set at the year at which the net present value of the project is maximum. Operating the project beyond this point will add more to costs than to benefits and hence will cause the net present discounted value of benefits to decline. It should be pointed out in this connection that

the discount rate chosen can affect the economic life of a project; high discount rates reduce the economic life and vice versa.

In the real world, however, costs and benefits accruing far into the future cannot be estimated with a high degree of accuracy. In practice, therefore, one resorts to a more subjective determination of project life, depending on such factors as the degree of risk and uncertainty perceived, the existence and nature of irreversibilities involved, and the degree of flexibility desired. A more cautious and conservative approach seems to be advisable if the project involves potentially irreversible effects which will have adverse consequences on human welfare and the environment as a whole.[1] While, in general, arbitrariness seems to be unavoidable in determining the planning horizon, the need to avert risk and uncertainty and the desire to increase flexibility and minimize irreversibility require that a relatively short planning horizon instead of the physical life of the project be adopted.

F. Risk and Uncertainty

Despite persistent efforts on the part of economic theorists to improve and refine prediction and forecasting techniques, economic science is still very far from being

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[1] Charles W. Howe, Benefit-Cost Analysis for Water System Planning, p. 80.

able to accurately predict future states of an economy. Future economic events always have some risk and uncertainty associated with them. Estimates about the future, especially economic estimates, cannot be made with full knowledge. Since the economic life of investment projects invariably extends over a long period of time, project analysts cannot estimate future benefits with complete certainty.

Risks and uncertainties associated with an investment project could arise from unanticipated technical failure of the project, from natural disasters, or from unpredictable changes in the economic environment and technology. In practical project evaluation, while some economic estimates based on a priori knowledge or statistical expectations can be made with some degree of probability, no degree of probability can be attached to certain other estimates or expectations. Each of these types of outcomes must be provided for if their unfavorable impact is to be avoided or at least the major part of it averted. It is therefore worthwhile to examine some of the adjustments and corrections that can be made for risk and uncertainty.

1. Risk

Risk involves those future outcomes which can be estimated with a certain degree of a priori or statistical

probability.[1] In other words, a probability distribution can be specified for risky events. Risky situations are, therefore, likely to be relatively easier to handle than uncertain outcomes in project evaluation.

Once the probability distribution of future outcomes is known, different methods exist for incorporating the associated risks in project analysis. For instance, means and variances can be used in the objective function to specify the range of values to be optimized.[2] Specified probabilities of various outcomes can also be used in direct decision-making by determining the expected values of future benefits or costs.[3]

Although the use of probability and other abstract decision theories such as those dealing with "maximization of expected utility" are intellectually appealing, they are generally impracticable and hence do not provide an adequate guide in empirical project evaluation.[4] In practice, therefore, the economist will have to resort to the

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[1] Frank H. Knight, Risk, Uncertainty and Profit (Boston: Houghton Mifflin Company, 1921), Chapter VII.

[2] R. Rees, "Public Sector Resource Allocation Under Conditions of Risk," Essays in Modern Economics: The Proceedings of the Association of University Teachers of Economics, Aberystwyth, 1972 (Dorking, Great Britain: Adlard and Son, 1973), pp. 110-134.

[3] E.J. Mishan, Cost-Benefit Analysis, pp. 282-284.

[4] Ibid., p. 297.

less elegant but more practical techniques of adjustment for risk.

Three more practical but crude risk adjustment techniques seem to be widely used by engineers and economists in project design and feasibility analysis.[1] These techniques are: (1) contingency allowances which arbitrarily raise certain categories of costs by a certain percentage or reduce benefits through price assumptions which are below expected prices; (2) a limit to planning horizon shorter than physical life and also shorter than expected economic life; and (3) the use of a risk premium in the discount rate.

These are for the most part arbitrary and generally conservative techniques and they seem to be aimed at averting or minimizing risk. Obviously, there is a price to be paid for greater security, and being unduly conservative can result in the rejection of viable and desirable projects. To reduce the arbitrary and extremely conservative nature of these adjustments, it may be useful to establish values of "pessimistic," "normal" and "optimistic" outcomes and then conduct a sensitivity analysis to determine the stability of the solution obtained. In cases where large statistical observations of the variables in question (for instance, prices and yields) are availble, the mean

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[1] Otto Eckstein, "A Survey of the Theory of Public Expenditure Criteria," p. 469.

and standard deviations can be employed to determine the three critical values. The final decision can then be made on the degree of relative confidence that the decision-maker has in each of the three values.

2. Uncertainty

As already mentioned above, uncertainty refers to classes of future events for which a probability distribution cannot be specified. The information available about these events is too inadequate to allow any specification of probabilities about their behavior.

Although the problem of how to handle uncertainty in economics is still far from being satisfactorily resolved, some theoretical approaches for decision-making under uncertainty have been developed. Game theory is one of the interesting theories in this regard. The minimax principle, which attempts to minimize losses if the worst of the possible outcomes occurs, and the maximum principle, which chooses the worst of the best possible outcomes, are the well known game theoretic approaches that can be employed to handle uncertainty.[1]

The more practical approaches to uncertainty, however, include built-in project flexibility which allows for adjustment as new information becomes available, limiting

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[1] For a review of game theory, see: R.D. Luce and H. Raffia, Games and Decisions (New York: John Wiley, 1957).

projects to reasonable sizes, minimizing irreversibilities, and developing projects by stages so that huge and costly mistakes can be avoided.

G. "With" and "Without" Comparison

Changes in the project area are likely to occur naturally even in the absence of a project. It is therefore incorrect to attribute all the changes occurring after a project is established entirely to the project. A realistic assessment of the relative merit of the project consequently requires contrasting the situation "with" the project to that "without" the project. For the project to be judged desirable it must show potential net benefits that are larger than would have been obtained "without" the project.

H. Sensitivity Analysis

Projects are generally subject to a high degree of uncertainty. Single value expectations in the crucial variables of price, yield, discount rate, economic life of project, etc. may fail to be realized and such eventualities must be anticipated and provided for in advance if unfavorable results are to be minimized or avoided. Sensitivity analysis is a way of assessing the impact of changes in expected price, yield, discount rate, project life or delay in construction periods on the net benefit of the project. The effect of unfavorable changes in these para-

meters on the social profitability of projects can be assessed by substituting the new values for initially expected values. Based on the outcome of sensitivity analysis, then, a contingency plan that will help avert or minimize the effect of unfavorable changes can be developed.

Financial Analysis

In contrast to economic analysis, financial analysis is concerned with purely financial costs and revenues of a project. Its main purpose is to evaluate the various methods of project financing and cost repayment. Unlike economic analysis, financial analysis relies strictly on prevailing market prices to evaluate the annual project revenues and costs.

In the context of the Ethiopian economy, two areas of project financing seem to be of major concern. The first involves the financing of imported goods and services. Public projects of the kind envisaged in this study will require a considerable amount of imported materials both during initial construction and for annual operation, maintenance and replacement of the project facilities. Fuel, fertilizer and farm machinery required for farm operations will also have to be imported from abroad. A sufficient amount of foreign exchange must, therefore, be available to finance these needed imports.

Once the absolutely necessary foreign exchange costs

of the project have been determined, funds may be acquired through a range of alternatives. The most obvious alternative, of course, is to use part of current foreign exchange earnings to import materials for the project. This might involve using uncommitted earnings or diverting funds from other (preferably luxury) imports to materials needed for the project. However, since annual foreign exchange earnings in Ethiopia are extremely limited, there may not be sufficient uncommitted funds available to pay for the needed imports. Although eventually all imports will have to be paid for from export earnings, the Government can borrow abroad for the immediate purpose of financing the foreign exchange cost of the project. Normally, a wide range of foreign lending sources, both private and government, are available. In some instances, it may be possible to work out bilateral or multilateral arrangements with supplying countries. Aid donor countries might also be interested in financing an economically viable project. While there are indeed a large number of alternatives for acquiring capital abroad, each alternative must be carefully weighed with regard to terms, conditions, and consistency with national and project objectives.

The second area of concern with regard to project financing is how to finance the purely domestic cost of the project. Under normal circumstances the government could borrow from the National Bank (credit creation), borrow from the public through the sale of bonds, or raise

the taxes. In Ethiopia, absence of a well developed capital market limits the possibility of financing the project by issuing bonds. Therefore, deficit financing and general tax revenues seem to be the only viable alternatives available to the government for financing investment projects. The choice of the better alternative, of course, depends on social, political and economic factors. It is quite conceivable that the government may not find it socially and politically expedient to increase general taxes to finance the project. Although under conditions of widespread unemployment and depressed general price levels deficit financing can be both simple and advantageous, projects will have to be financed from general tax revenues in situations where the economy is facing inflationary tendencies or when the project is large enough to raise the general level of prices. The merit of each method of financing must therefore be carefully assessed in light of the prevailing or expected state of the economy.

Closely associated with the problem of project financing is the question of cost repayment. The public decision-making entities must decide whether the project cost should be reimbursed, and if so, how much of it should be repaid, who should pay it, and how the repayment should be collected. The repayment problem becomes particularly complex if the general rule that payment should be made in proportion to benefit derived is to be applied. Characteristically, social benefits accruing from a public

project are so widely distributed throughout the economy that seldom, if at all, can they be traced to the final point of incidence. Of course, there are certain immediately identifiable beneficiaries, but it would be unfair to expect them to bear all the costs since they do not derive the entire benefits. If a repayment policy is to be fairly and equitably applied, it will be necessary to more accurately identify and measure all the direct and indirect benefits that flow from the project. The incidence of these benefits must also be carefully identified. This, of course, is a formidable task and would require the use of complex techniques such as input-output analysis. However, once the recipients of the benefits have been properly identified, various approaches can be used for collecting the repayment. A simple workable approach would be to apply a direct user charge, which may have a fixed and variable component, to the direct beneficiaries and use general taxation for collecting repayment from indirect beneficiaries. Other forms of repayment schemes may be more applicable to specific situations; therefore, it is useful to investigate various viable forms of repayment schemes for each project before a final decision is reached.

Summary

The analytical tools of recursive programming and

benefit-cost analysis were described in this chapter. Recursive programming is an extension of linear programming designed to overcome the non-dynamic limitations of ordinary linear programming. The basic elements of linear programming, namely, the objective function, the resource constraints, and the non-negativity constraints, and most of the assumptions of linear programming apply to recursive programming as well. In addition, however, time enters the recursive programming analysis in a fundamental way. Time is incorporated into a recursive model through the use of flexibility coefficients that help tie either the objective function, the constraint matrix, or the right-hand-side parameters of a model at a given period to a model of a preceding period. The estimation of the flexibility coefficients and the year-to-year changes in any of the parameters, therefore, represent a crucial aspect of recursive programming. Once the flexibility coefficients are estimated, a sequence of linear programming models are developed for each year over the planning horizon. The solution procedures are quite similar to those of ordinary linear programming. The simplex algorithm can be used to solve each of the sequential models or a computer program can be developed to solve the entire sequence in one run.

Benefit-cost analysis is an analytical approach that attempts to describe and quantify the social costs and benefits of public investment or public economic policy.

However, the practical application of this seemingly simple approach involves a great many problems. First, the specifications of a properly measurable social objective presents a serious difficulty. A widely agreed upon and operational index of social welfare has so far eluded the efforts of economists. The maximization of real national income, although the most widely used social objective, fails to provide an accurate measure of social welfare because it ignores distributional issues and assumes the marginal utility of income to be equal for all individuals in the society. Second, the valuation of costs and benefits in the face of externalities, market imperfections, and extramarket goods also poses major difficulties because under these and related circumstances, market prices do not carry full information about costs and benefits. Third, additional problems revolve around the choice of the social discount rate and the project selection criteria. Finally, controversy over the length of the planning horizon and the treatment of the complex problems of risk and uncertainty further complicate benefit-cost analysis.

Characteristically, benefit-cost analysis encompasses both economic and financial analyses. In economic analysis, the concern is with the overall efficiency of resource allocation. The main objective here is to determine whether a project can yield sufficient positive net social benefits to justify its construction relative to

other investment opportunities in the economy. Economic analysis also recognizes that not all costs and benefits of a public project may have monetary value and that market prices may not always measure the true social costs and benefits of goods and services. In financial analysis, on the other hand, the emphasis shifts to consideration of direct annual revenues and costs measured in market prices. The overriding concern in financial analysis is whether the annual revenues will be sufficient to cover the amortized and operating costs of the project in question. Consequently, the careful examination of alternative forms of financing, the assessment of the incidence of benefits and costs, the method of product pricing or the determination of the method of cost repayment are all considered vital aspects of financial analysis.

In conclusion, therefore, the two techniques described in this chapter, namely, recursive programming and benefit-cost analysis, do complement each other and they seem to be quite appropriate for the purpose at hand. Undoubtedly, if carefully, prudently and competently applied, the two techniques, in combination, can provide useful and realistic results in water project analysis. The empirical analysis presented in the following chapter will attempt to demonstrate this.

CHAPTER VI

EMPIRICAL ANALYSIS

The implications of the theoretical analysis presented in the preceding chapters suggest that the available empirical evidence be examined carefully in order to establish whether public investment in agricultural water development in Ethiopia will be economically feasible. Associated with the question of economic feasibility is the need to determine whether such an investment can significantly contribute to the expansion of food production and employment. The purpose of this chapter, therefore, is to bring together and analyze the data relevant to the empirical evaluation of the study. More specifically, this chapter seeks to outline the data sources, the valuation procedures, and the overall empirical analysis of the study. The results of the empirical analysis, however, are summarized in the subsequent chapter.

Source of Data

Data for this analysis were collected from a variety of sources. The most important sources were the field data compiled by the Blue Nile and Awash Basin surveys. The basic engineering and agronomic information for the

Megech Project were obtained primarily from the Blue Nile survey conducted jointly by the Ethiopian government and the Bureau of Reclamation of the United States Department of the Interior in the 1960's. The figures, however, have been reviewed and appropriately adjusted to reflect the changes that have occurred since the survey was published in 1964. The corresponding information for the Kesem Project, on the other hand, were derived from the extensive Awash River Basin survey carried out jointly by the Ethiopian government and the F.A.O./U.N. Special Fund and subsequently published in a series of five volumes in 1965. These data have also been modified, wherever necessary, to reflect changes that have occurred since the figures were published.

Information regarding recommended rates of fertilizer application and yield levels were obtained from the national fertilizer trial programs and the experimental results of the Institute of Agricultural Research and the College of Agriculture Experiment Stations. The annual reports of the National Crop Improvement Committee and the large commercial and state farms were useful sources of dryland and irrigated yield levels. Commodity prices and market information were obtained from the Ethiopian Grain Board, the Ethiopian Grain Corporation, the National Bank of Ethiopia and the various publications of the Ethiopian Central Statistical Office. Labor requirements, machinery performance rates as well as machinery and other input

prices were obtained from commercial and state farms, College of Agriculture publications, machinery dealers, and farm supply companies. Data from the files and the large number of volumes published by the Stanford Research Institute as part of the Agro-Industrial Survey of Ethiopia were also heavily drawn upon at various stages of the analysis.

Additional information was also obtained from official and unofficial sources in the Ministry of Agriculture, the Planning Commission, the Awash Valley Authority, the National Water Resources Commission, the Technical Agency of the Ethiopian Government, and the Ethiopian Ministry of Industry and Commerce. These sources were further supplemented by other sources including published and unpublished theses on Ethiopian agriculture, independent studies and reports by individual experts, books and library materials, F.A.O. and related U.N. publications, as well as personal knowledge and private correspondence with Ethiopian economists, agronomists, administrators, and farm managers thoroughly knowledgeable about Ethiopian economic and agronomic conditions.

Valuation Procedure

The accounting of costs and benefits in this study follows a national rather than a regional or local "stance". The focal point of the evaluation procedure is overall

social costs and benefits as opposed to regional, local, or private costs and benefits.

The major portion of the costs and benefits considered relevant to this analysis are those for which market values are available or can be readily imputed with an acceptable degree of accuracy. An attempt has not been made to quantify and incorporate the extramarket benefits and costs of the proposed projects in the quantitative analysis. But the nature and magnitude of the extramarket benefits and costs have been discussed so as to provide the decision-makers with additional information that they may find useful when assessing the potential impacts of these projects.

Measurement of Costs

Land, labor, and capital constitute the resources needed for the construction and operation of the projects envisaged in this study. To arrive at the true cost of undertaking the projects, it is essential to determine the social opportunity cost of using a unit of each of the three resources required for establishing and operating the projects. Under Ethiopian conditions, the valuation of land, labor and capital poses difficulties peculiar to each factor. These peculiarities will be discussed below.

A. Land

According to the Rural Land Proclamation of March

1975,[1] all land in Ethiopia has been nationalized and although individual farm operators may have usufructuary rights for up to 10 hectares of land, transfer of same through sale or inheritance has been banned. There is therefore no market value for land in Ethiopia. The absence of a market value for land does not, however, preclude the fact that land has a social opportunity cost and this fact must be recognized if widespread misallocation of this vital and scarce resource is to be avoided.

In this study, it is assumed that the government will make land available to the proposed projects free of charge. This assumption is consistent with the declared policy of the present government, which tends to encourage cooperative and state farms. Nevertheless, an imputed rent for land based on previous experience and level of productivity of the particular tract of land must be included as a land cost to ensure that land will not be misallocated. Although this cost may not in fact have to be paid, charging the imputed rent of land to the project serves as a reasonable safeguard against the possibility of misallocating land. Accordingly, an imputed land rent for each type of land anticipated to be utilized in each project was included to account for the cost of the land resource.

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[1] Provisional Military Government of Ethiopia, "Rural Land Proclamation," Ethiopian Herald, March 4, 1975.

B. Labor

The valuation of labor services in Ethiopia presents certain peculiar problems as well. To begin with, the labor market in Ethiopia is not well developed. It is therefore premature to speak of market-determined wage rates for the labor force still employed within the traditional agricultural sector. In this sector, hired labor constitutes a very small proportion of the labor force, and almost all the labor input is supplied by family members. Production in this sector is also primarily for family consumption and only a very small share of the produce is marketed.

Whether there is a well developed market or not, the value of labor services must, among other things, have some relationship with labor productivity. Labor productivity, of course, is in turn related to the skill and dexterity of the labor force. Therefore, in order to arrive at a realistic assessment of the social value of labor services in Ethiopia, it is necessary to divide the total labor force into two groups: skilled and unskilled workers. Unskilled labor by far outnumbers skilled manpower in Ethiopia. Although not properly documented, there seems to be widespread underemployment of unskilled labor throughout the country.

While the rate of unemployment varies from region to region, the available evidence seems to suggest that open unemployment in Ethiopia is more an urban than a rural

phenomenon.[1] The traditional rural sector seems to mask open unemployment into disguised unemployment through such mechanisms as the extended family system and work sharing arrangements. Nevertheless, there appears to be little disagreement that a significant number of unskilled workers can be withdrawn from rural Ethiopia without discernably reducing the level of agricultural output. The marginal product of unskilled labor in Ethiopia, therefore, appears to be very close to zero.

In the presence of high levels of general unemployment and underemployment of unskilled labor in the nation, the social opportunity cost of labor can be presumed to be zero. This means that the nation will not forego any goods and services when the new project employs heretofore unemployed workers.

This situation can also be looked at in a different light. While the project still has to pay wages comparable to those in other similar enterprises regardless of whether there is unemployment or not, such wage payments do not represent an appropriate social cost from the national point of view. Therefore, the appropriate accounting price of unskilled labor under Ethiopian conditions is zero.

The situation with skilled labor, however, is different. Skilled manpower is in short supply in Ethiopia. The

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[1] For a discussion on this point see Yilma Teklemariam, "Issues in Labor Unemployment and Migration in Ethiopia."

projects considered in this study will have to compete with other projects and sectors of the economy for the limited supply of trained and skilled workers.

Another important consideration in this connection is the fact that skilled workers have a tendency to congregate in urban centers and, unlike unskilled workers, cannot be recruited locally. Skilled workers must therefore be recruited in the big cities and transported to the project site. To obtain the qualified and competent employees required by the projects, the level of salaries, compensations and fringe benefits offered must be of a magnitude sufficient to induce them to work at the project site. In view of these considerations, skilled labor in this study is valued at Addis Ababa salary levels plus transportation costs to the project site plus a specified percentage of the basic salary, consistent with the civil service scale, for hardship allowance.

C. Capital

The term capital as used here encompasses all the resource inputs other than labor and land required for the establishment and successful operation of the projects considered in this study. It is a category that includes goods and materials ranging from cement and reinforcement steel to farm machinery and implements considered essential to bring forth the project output. In determining the total capital expenditures, distinctions are made between

home produced and imported goods.

Not all capital goods and services required for the construction, maintenance and operation of the projects are expected to be home produced Ethiopian products. A fair portion of the capital equipment and production inputs (approximately 40 percent of total capital expenditure) are expected to be imported. The valuation of goods coming from each of these sources requires some complex procedures. Although these products have market prices, it is often necessary to adjust the prevailing market prices either for subsidies, taxes, or overvalued exchange rates so as to derive accounting prices that more accurately reflect their true social costs. The general approach used in this study for the determination of the capital expenditure is summarized below.

1. Domestic Capital

The cost of the materials and resources obtained from domestic sources is computed on the basis of the Addis Ababa wholesale price less subsidies and indirect taxes plus transportation cost to the project site. Addis Ababa was chosen as a source of supply for capital items after examination of other viable sources of supply. For most of the goods and materials considered, the appropriately adjusted Addis Ababa wholesale price compared favorably with other competitive supply sources. It has also been found that Addis is a more reliable source of supply

for most of the materials needed. As the major market center in the country, Addis also offers possibilities of bulk purchase of supplies which can lead to scale economies.

2. Imported Capital

The goods expected to be imported for project purposes range from construction and irrigation equipment to farm production inputs such as fertilizer, pesticides, and improved seeds. In the presence of such factors as import subsidies on farm equipment and farm fuel and an overvalued currency, there is bound to be a divergence between the domestic market price of imported goods and their true social opportunity cost. In Ethiopia, imported goods in general are subject to import duties and transaction taxes. However, according to the Ethiopian Investment Proclamation No. 242 of 1966,[1] agricultural and industrial machines, implements and appliances or parts thereof which are imported for exclusive use in agricultural and industrial enterprises are exempt from import duties and taxes. In this study, therefore, imported goods needed for the project are valued at c.i.f. port of entry plus transport charges to the specific project area.

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[1] William L.K. Schwarz, Paulos Abraham and Kifle-Mariam Zerom, Industrial Investment Climate in Ethiopia, Report No. 2 (Menlo Park, California: Stanford Research Institute, July, 1968), pp. 13-73.

Measurement of Benefits

Measuring the benefits of a public project basically involves the task of measuring the users' or consumers' willingness to pay for the output of the project. If the goods to be produced are marketable, appropriately adjusted market prices can be taken to represent the consumers' willingness to pay for the projects output. The problem of measuring benefits, however, becomes very complex if the goods to be produced have no observable market value.

The outputs of the projects proposed here are largely marketable. Therefore, their direct social benefits can be estimated on the basis of expected yields and prices. Accordingly, yield levels both "with" and "without" the projects were carefully estimated for each of the alternatives considered. In estimating yields, it was assumed that a period of ten years of operation would be required for the projects to achieve full irrigated yield levels. The ten year lag period will hopefully allow sufficient time for educating farmers in the techniques of irrigation farming and will facilitate a smooth, orderly transition from dryland farming to irrigation agriculture.

The prices used to value the outputs are the immediate post harvest farm gate prices of 1970. Imputed farm gate prices were developed for each project area by adjusting Addis Ababa wholesale commodity prices for transaction taxes and transport charges.

A portion of the annual output is expected to be

exported in order to obtain foreign exchange needed to operate the project. The amount of foreign exchange earnings that can be raised by exporting project outputs is computed by adjusting the f.o.b. price of the commodity at the port of exist for export taxes and transportation charges. Finally, due to lack of adequate data on indirect benefits and costs, only direct costs and benefits are quantified in this study. But to provide the policy maker with the complete picture, the projects' possible impact on indirect benefits and costs have been enumerated. Extra-market costs and benefits also have not been quantified, but their possible magnitudes and impacts are discussed.

To eliminate the effect of inflation and measure only real changes in output, all prices and costs are based on 1970 Ethiopian dollars. Foreign exchange rates are also computed on the basis of the 1970 fixed rate levels.[1] It should be mentioned that dramatic changes have occurred in the foreign exchange market since 1970. The United States dollar, the currency on which the Ethiopian dollar is pegged, was devalued in 1971 and global inflation has caused the price of manufactured goods to rise dramatically. The prices of petroleum and fertilizers, in particular, have skyrocketed since 1971.

Although these changes are recognized and more changes

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[1] Eth. $1.00 = $0.40 U.S. prior to the 1971 U.S. devaluation.

are likely to happen in the future, it can be safely assumed that in the long run changes in costs and benefits arising from inflationary changes will have more or less offsetting net effects. Specific costs, yields, and prices for each of the alternatives evaluated in this study are presented elsewhere in this chapter.

Planning Horizon

The planning horizon for the analysis of the projects considered in this study was set at 40 years. Undoubtedly the useful life of the projects will be considerably longer than 40 years. A more conservative planning horizon has been adopted here partly to account for risk and uncertainty. As a further adjustment for risk and uncertainty, the salvage value of the projects at the end of the 40 years has been set at zero. Although crude and arbitrary, these adjustments seem to be acceptable for practical purposes.

Discount Rate

The capital market in Ethiopia is extremely limited. Government bond sales are almost nonexistent. The main source of long term investment credit in Ethiopia at the present time is the Agro-Industrial Development Bank of Ethiopia. The Bank's interest rate varies among sectors. Industrial loans are charged at higher rates than agricul-

tural loans. At present, the Agro-Industrial Bank charges 10 percent for agricultural loans and 12 percent or more for long term industrial loans. Most observers of the Ethiopian capital market feel that because of the scarcity of capital in the country, an interest rate of around 15 percent would closely approximate the social opportunity cost of capital. Considering all the relevant factors, three discount rates, i.e., 10 percent, 12 percent and 15 percent, were used to obtain three different benefit-cost ratios and three net present values for each of the alternatives analysed.

Economic Analysis of the Megech River Project

As has already been pointed out, the Megech Project involves the development of supplemental irrigation as well as the provision of rural water supply both for domestic and stock use in a representative area of the Ethiopian highlands. The benefits and costs of this project are compiled on a "with" and "without" basis. A number of alternatives were considered under each of these propositions.

Benefits and Costs "Without" the Project

Two alternatives were considered to be the most probable courses of development in the foreseeable future

in the absence of the project in the Megech Project area.

A. <u>Alternative I</u>

Alternative I assumes the present state of agricultural technology will continue far into the future with very little change. The present subsistence nature of the production pattern is expected to remain virtually the same over at least the coming 40 years.

Given the historical trend in agricultural production over the past three decades, it is not unrealistic to expect that conditions may not improve substantially in the project area in the absence of the proposed project. Indeed, from the vantage point of a pessimistic observer, this alternative would seem to be a reasonable and defensible one.

To evaluate the merit of this alternative, a farm budget was set up using 1970 yields and prices as well as existing crop mixes. The present value of the net social benefit that can be expected from the entire project area of 5,890 hectares over the next 40 years was then derived. Table 6.1 shows the yields, prices and cost of production per hectare for the different crops presently cultivated and projected to be grown "without" the Megech Project under Alternative I.

B. <u>Alternative II</u>

The second alternative, which under normal circumstances represents a more reasonable and more probable

TABLE 6.1

AVERAGE CROP YIELDS, IMPUTED FARM GATE PRICES AND ESTIMATED COST OF PRODUCTION PER HECTARE, ALTERNATIVE I TRADITIONAL PRACTICES "WITHOUT" THE MEGECH RIVER PROJECT

Type of Crop	Average Yield 100 kg/ha	Imputed Farm Gate Price Per 100 kg	Estimated Cost of Production $/ha
		In 1970 Eth. Dollars	
Barley	12.7	18	209.7
Maize	27.5	18	252.0
Sorghum	25.5	20	253.0
Teff	11.6	28	300.8
Wheat	11.6	24	219.2
Linseed	6.6	25	211.2
Noogseed	6.0	26	234.4
Horsebeans	12.5	15	201.5
Haricotbeans	12.0	28	205.2
Lentils	8.0	27	210.0
Fenugreek	7.5	25	219.5
Pepper	5.3	52	245.0
Potatoes	66.2	10	402.5
Onions	49.1	10	408.7

SOURCES: Imperial Ethiopian Government, Ministry of Agriculture Extension Service, and F.A.O., "Freedom from Hunger Campaign: Fertilizer Demonstration Program 1969/70" (Unpublished Report, Addis Ababa, n.d.). U.S.D.I., Bureau of Reclamation, "Appendix VI. Agriculture and Economics," Land and Water Resources of the Blue Nile Basin in Ethiopia (Washington, D.C.: U.S.D.I., 1964), p. 233.

development in the area in the absence of the project, assumes limited technological improvement in the pattern of agricultural production. It is primarily based on two important factors currently at work in Ethiopian agriculture, namely, the implementation of the "minimum package" program by the Ethiopian Ministry of Agriculture, and recent political and institutional changes, particularly those relating to land reform and regional administration.

These developments are already beginning to show some positive impact on Ethiopian agriculture, and they promise even better results in the future. The "minimum package" program launched during the Third Five Year Development Plan (1968-73) seems to have increased the availability and popularity of fertilizer, credit and orderly marketing among increasing numbers of peasant producers. As a result of this program, the farmers in the proposed project area have been exposed to the use of fertilizer and some have even started applying fertilizer to their fields.[1] The use of fertilizer, along with the use of high yielding crop varieties increasingly being made available from the various agricultural research stations in the country, will likely lead to increases in yield and farm income even in the absence of the kind of projects envisaged in this study.

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[1] Imperial Ethiopian Government, Ministry of Agriculture, Planning and Programming Department and Planning Commission Office, "Preliminary Agricultural Investigations in the Lake Tana Region" (Unpublished Report, Addis Ababa, I.E.G., April, 1972), pp. 11-15.

In addition, the recently proclaimed land reform law and planned improvements in the agricultural marketing system seem to provide the necessary institutional support for the development of peasant agriculture in Ethiopia. In general, all these factors tend to point in the direction of improvements in the pattern of peasant agricultural production even without the introduction of the type of projects proposed here. Therefore, a more realistic alternative for developments "without" the project should assume some technological and institutional change which would result in positive changes in yield levels.

Alternative II differs from Alternative I in that it assumes the use of commercial fertilizer, improved seeds, and improved cultural practices and a favorable institutional and political environment. The method of traction, the labor intensive character and the mainly subsistence orientation of the production pattern are assumed to remain the same. Table 6.2 presents the yields and prices used in the evaluation of Alternative II. The results of the analysis of both alternatives are presented in Chapter VII.

Benefits and Costs "With" the Project

The engineering design of the Megech Project calls for the direct pumping of water from the Megech River in order to provide water for supplemental irrigation and community use. An irrigable area of 5,890 hectares will be commanded by the irrigation system and the community

TABLE 6.2

AVERAGE YIELDS, IMPUTED FARM GATE PRICES AND ESTIMATED COSTS OF PRODUCTION PER HECTARE, ALTERNATIVE II - IMPROVED PRACTICES "WITHOUT"

THE MEGECH RIVER PROJECT

Type of Crop	Average Existing Yields 100 kg/ha	Expected Yields with Improved Practices 100 kg/ha	Imputed Farm Gate Prices $/100 kg	Estimated Cost of Production $/ha
			In 1970 Eth. Dollars	
Barley	12.7	20.7	18	272.9
Maize	27.5	39.9	18	256.6
Sorghum	25.5	35.3	20	255.8
Teff	11.6	14.8	28	386.1
Wheat	11.6	16.5	24	388.6
Linseed	6.6	10.8	25	263.6
Noogseed	6.0	14.0	26	368.6
Horsebeans	12.5	20.4	15	215.8
Haricotbeans	12.0	16.0	28	238.8
Lentils	8.0	13.0	27	218.8
Fenugreek	7.5	12.0	25	265.8
Pepper	5.3	8.6	52	293.8
Potatoes	66.2	107.8	10	405.8
Onion	49.1	80.0	10	406.8

SOURCES: Imperial Ethiopian Government, Ministry of Agriculture, Extension Service, and F.A.O., "Freedom from Hunger Campaign: Fertilizer Demonstration Program 1969-70" (Unpublished Report, Addis Ababa, n.d.); Carl F. Miller, et al., Systems Analysis Methods for Ethiopian Agriculture, (Menlo Park, California: Stanford Research Institute, 1968); National Crop Improvement Committee, Results of the National Crop Trials 1972 (Addis Ababa: Institute of Agricultural Research, 1974).

water supply system is designed to provide the daily water requirements of over 25,000 people. Energy for the pumping plant is expected to be obtained from a hydro-plant at Bahrdar, about 60 kilometers south of the project area.

The irrigation system is assumed to be phased-in over a ten year period, thus allowing the farmers sufficient time to adjust to the new system of irrigation farming. The irrigated yield levels are also assumed to be fully realized by the tenth year.

Although a relatively long lag period has been assumed to bring the entire area under irrigation, the land will still be used during the non-irrigation period when rainfall is available for crop cultivation. The irrigation season will extend from October to the end of May, while June through September forms the non-irrigation season.

The cost of establishing and operating the project has two major components: project costs and associated costs. Each of these cost items will be briefly discussed below.

A. Project Costs

The project costs include the value of goods and services used in establishing, maintaining and operating the pumping plant, the distribution and drainage systems, the community water supply centers, access roads, and other related service facilities such as schools, clinics,

administrative centers and community halls. Land development and interest charges during construction are also considered part of the project cost. Table 6.3 shows the estimated project costs over the 40 year planning period. Column (1) of this table gives the planned level of capital investment for each of the ten years of project development. Annual interest during construction, shown in Column (2) of Table 6.3, is computed using the following formula of simple interest.

$$I^1 = \frac{(K \times r)}{2} ,$$

where I = the annual interest charge,

K = the annual capital investment,

r = the rate of interest.

The interest rate (r) used in this analysis is 10 percent, which is the level of interest charged by the Agro-Industrial Development Bank of Ethiopia on agricultural loans.

The annual operation and maintenance cost of the project is presented in Column (3). This cost covers such outlays as the energy cost required to operate the pumping

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[1] Division by two is necessary because on the average only half of the total annual investment is tied up in the project over the entire year.

TABLE 6.3

ESTIMATED COST OF MEGECH RIVER PROJECT

Planning Period	(1) Capital Investment	(2) Interest During Construction	(3) Operation and Maintenance Cost	(4) Replacement Cost	(5) Land Development Cost	(6) Total Project Cost
			In '000 of 1970 Eth. Dollars			
0	2,120.10	106.01	--	--	--	2,226.10
1	1,978.76	98.94	69.75	--	72.51	2,219.95
2	1,696,08	84.80	139.50	--	72.51	1,992.89
3	1,554.74	77.74	209.25	--	72.51	1,914.23
4	1,413.40	70.67	279.00	15.55	72.51	1,851.12
5	1,272.06	63.60	348.75	16.96	72.51	1,773.88
6	1,130.72	56.54	418.50	18.37	72.51	1,696.64
7	989.38	49.47	488.25	19.74	72.51	1,619.40
8	848.04	42.40	558.00	28.27	72.51	1,549.22
9	706.70	35.03	627.75	26.86	72.51	1,468.84
10	424.02	21.20	697.50	29.68	72.51	1,244.91
11	--	--	697.50	35.34	--	732.84
12	--	--	697.50	36.75	--	734.25
13	--	--	697.50	40.99	--	738.49
14	--	--	697.50	39.58	--	737.08
15	--	--	697.50	42.40	--	739.90
16	--	--	697.50	43.82	--	741.32
17	--	--	697.50	46.64	--	744.14
18	--	--	697.50	52.30	--	749.80
19	--	--	697.50	55.12	--	752.62
20	--	--	697.50	53.71	--	751.21
21	--	--	697.50	56.54	--	754.04

TABLE 6.3 (CONTINUED)

Planning Period	(1) Capital Investment	(2) Interest During Construction	(3) Operation and Maintenance Cost	(4) Replacement Cost	(5) Land Development Cost	(6) Total Project Cost
			In '000 of 1970 Eth. Dollars			
22	--	--	697.50	57.95	--	755.45
23	--	--	697.50	55.21	--	752.71
24	--	--	697.50	46.56	--	744.06
25	--	--	697.50	43.96	--	741.46
26	--	--	697.50	42.54	--	740.04
27	--	--	697.50	41.00	--	738.50
28	--	--	697.50	38.18	--	735.68
29	--	--	697.50	36.89	--	734.39
30	--	--	697.50	34.06	--	731.56
31	--	--	697.50	31.40	--	728.60
32	--	--	697.50	28.41	--	725.91
33	--	--	697.50	29.12	--	726.62
34	--	--	697.50	26.86	--	724.36
35	--	--	697.50	22.61	--	720.11
36	--	--	697.50	21.20	--	718.70
37	--	--	697.50	20.79	--	718.29
38	--	--	697.50	19.37	--	716.87
39	--	--	697.50	18.96	--	716.46
40	--	--	697.50	16.73	--	714.23

SOURCE: U.S.D.I., Bureau of Reclamation, "Appendix VI: Agriculture and Economics," _Land and Water Resources of the Blue Nile Basin of Ethiopia_ (Washington, D.C.: U.S.D.I., 1964), p. 233.

plant, wages and salaries of personnel that will operate the project, and expenses required for the maintenance and up-keep of the project facilities.

The annual operation and maintenance cost starts at E $69,750 in the first year and increase to E $697,500 in the tenth year, after which time it remains constant for the next 30 years (Table 6.3). The projected increase in the operation and maintenance cost during the first ten years, of course, is closely related to the expansion of the project itself.

Another important item in the project cost is the replacement cost. Machines and equipment wear out or break down as time goes on. If the project is to produce the output it is designed to produce over its planned life time, it is essential that machines, equipment and facilities in general be kept at top operating condition. The annual replacement cost is therefore designed to cover the cost of repairing or replacing the various machines, equipment, and related facilities of the project as they wear out or break down.

Typically, replacement costs follow a certain profile. They are generally low in the first few years when facilities are still new, but gradually increase as machines age and approach the end of their expected useful life. Replacement cost is therefore likely to be high when the project reaches middle age, gradually declining as the project nears its expected life and machines and equipment are

allowed to wear out. Column (4) of Table 5.3 depicts the estimated annual replacement cost of the project over the 40 year period. This estimate is based on estimates of the life expectancy of the machines and equipment used in the project, the subjective probability of breakdowns and wear outs, and the period of time in the life of the project. The replacement cost and the operation and maintenance cost of the project constitute what is commonly known as the recurrent cost of the project.

The land development cost shown in Column (5) of Table 6.3 includes the funds required for leveling the farm land to be irrigated, laying out the fields, and putting in the supply and drainage ditches. Since equal areas of land are expected to be developed in each year of the ten year expansion period, the annual land development cost stays at E $72,506 throughout.

Column (6) of Table 6.3 presents the total estimated annual project cost. Obviously it is composed of the expenditure on capital investment, interest during construction, operation and maintenance cost, replacement cost and the cost of land development. After the tenth year, however, the annual project cost drops down to the cost of operation, maintenance, and replacement or the so-called recurrent costs of the project.

B. Associated Costs

Associated costs include the value of goods and ser-

vices other than project costs necessary to produce the direct and immediate output of the project. In this particular study, the direct cost of agricultural production and on-farm handling and storage constitute the associated cost.

The direct agricultural production costs are typically composed of the normal costs of carrying out the various farming operations. In Ethiopia, the range of farming operations vary crom crop to crop and from region to region. The major farming operations in the Megech Project area include plowing, seeding, cultivating, crop maintenance (weeding, nutrient and pesticide application, irrigation, etc.), harvesting, threshing, on-farm transportation, and storage. To arrive at the annual associated cost of the project, therefore, the cost of each of these operations for each of the types of crops selected to be grown in the project area must be carefully estimated. The annual associated cost of crop production was estimated using the following formula.

$$A_{jt} = \sum_{i=1}^{n} C_{ijt}H_{ijt}, \quad i=1,\ldots,n;\ t=1,\ldots,T;\ j=1,2,3 \tag{6.1}$$

$$C_{ijt} = \sum_{k=1}^{m} O_{kijt}, \quad k=1,\ldots,m \tag{6.2}$$

where A_{jt} = annual associated cost under the j^{th} farm management strategy at year t,

C_{ijt} = the per hectare production cost of crop i under strategy j at year t,

n = the number of crops considered optimal for the project area under the j^{th} strategy at year t,

H_{ijt} = the number of hectares of crop land allocated to crop i under the j^{th} strategy at year t,

O_{kijt} = the per hectare cost of carrying out farm operation k for crop i under strategy j at year t,

m = the number of farm operations under the j^{th} farm management strategy.

The procedure used in determining the associated costs of this project, as can be seen from (6.1) and (6.2) above, is somewhat complex. Clearly, different farm management strategies and different crop mixes in a given strategy can lead to different associated costs and, of course, different benefit levels. In view of these considerations, three different farm management strategies were specified. Subsequently, based on production cost estimates and specified resource restraints, an optimum crop mix was developed for each strategy using a ten year recursive program. The annual associated costs were then computed on the basis of the optimal crop mix under each strategy. The figures for each type of strategy are presented in Tables 6.4 through

6.12.

C. Gross Direct Benefits

Estimates of the annual gross direct benefits of the Megech Project, like the annual associated costs, were based on the annual optimal crop mix developed for the project area under each of the three farm management strategies considered. The annual gross direct benefits were determined using the average annual yield level of each crop in the optimal crop mix, the area allocated to each crop and the constant 1970 farm gate price for each crop. The following general formula was applied in estimating the annual direct gross benefits.

$$B_{jt} = \sum_{i=1}^{n} Y_{ijt} H_{ijt} P_i, \quad j=1,\ldots,m;\ t=1,\ldots,T \tag{6.3}$$

where B_{jt} = the direct gross benefit under j^{th} farm management strategy at year t,

Y_{ijt} = the average yield of crop i under j^{th} strategy at year t,

H_{ijt} = the number of hectares of crop land allocated to crop i under the optimal plan of strategy j at year t,

P_i = the imputed farm gate price of crop i in constant 1970 dollars.

The associated costs and direct benefits of the Megech Project were estimated under the following three farm management strategies.

1. <u>Strategy I -- Animal Powered Labor Intensive Operation</u>

This strategy rests on the assumption that heavy inputs of labor and animal traction will be used to perform the various farm operations. In a sense, this strategy is a direct continuation of the existing Ethiopian highland farming practices except for the introduction of irrigation, agricultural chemicals, some improved seed and improved storage facilities.

The types of crops considered under this strategy are exactly the same as those considered under alternatives "without" the project. Fortunately, improved varieties of some of these crops are becoming increasingly available from the various agricultural research stations in Ethiopia.

The merits of this strategy are obvious. The use of animal power as a source of traction is an already known and viable technology in the project area and in the Ethiopian highlands in general. Unlike the other strategies, which will be discussed shortly, this particular strategy does not require the use of relatively expensive, imported inputs such as modern machinery and petroleum products. The level of skill required to operate animal powered agriculture is not as complex as that required to operate and maintain mechanical power sources. Moreover,

because of its high complementarity with the labor input, a farm strategy based on animal powered technology would offer better employment opportunities relative to those strategies based on modern farm machinery. The employment generation capacity of this strategy is particularly significant for Ethiopia, where the creation of employment opportunities for the unemployed and underemployed is a matter of great urgency.

Despite its many advantages, this strategy also has some serious shortcomings. Under this strategy large areas of potentially productive crop land must be kept under pasture in order to produce sufficient fodder for the animals. As land becomes more scarce due to increases in population, this system may prove to be an inefficient method of producing food. Experience also seems to indicate that yields from animal plowed fields are not as high as yields obtained from machine plowed fields, other things being equal. It is therefore possible that gains from production efficiency derived from mechanized agriculture can offset any losses in employment and depletion of foreign exchange that may be associated with farm mechanization.

In view of the foregoing statement and realizing that the long run solution to the food problem in Ethiopia depends, among other things, on the utilization of some form of inanimate energy in the production process, two other alternative strategies based on mechanized farming have been considered.

The yields, prices, and production costs used in evaluating Strategy I have been itemized in Table 6.4. The per hectare production costs for the various crops were based on the number of farm operations required and the cost of performing each operation. To the operation costs were added the cost of supplies such as agricultural chemicals, seeds, sacks, and the fixed costs of depreciation, interest on investment, and land taxes. The cost of irrigation was not included as this was already considered in the project costs.

The following recursive program was used to derive an optimum crop mix for the Megech Project area under the animal powered strategy.

$$\text{Maximize } Z_t = \sum_{i=1}^{N} R_{it}X_{it}, \quad N=14;\ t=1,\ldots,T$$

subject to:

$$X_{1t} + X_{2t} + X_{3t} + \ldots + X_{14}t \leq 5890\ (0.10)(t)$$

$$- X_{1t} \leq - X_{1t-1} \quad (1.16)$$

$$- X_{2t} \leq - X_{2t-1} \quad (1.18)$$

$$- X_{3t} \leq - X_{3t-1} \quad (1.10)$$

TABLE 6.4

CROP YIELDS, IMPUTED FARM GATE PRICES AND ESTIMATED COST OF PRODUCTION PER HECTARE - STRATEGY I: ANIMAL POWERED OPERATION - MEGECH RIVER PROJECT

Type of Crop	Average Existing Yields 100 kg/ha	Expected Irrigated Yields After 10 Years 100 kg/ha	Imputed Farm Gate Prices $/100 kg	Estimated Cost of Production $/ha
			In 1970 Eth. Dollars	
Barley	12.7	24.6	18	272.9
Maize	27.5	49.9	18	256.6
Sorghum	25.5	45.6	20	255.8
Teff	11.6	19.0	28	386.1
Wheat	11.6	21.2	24	388.6
Linseed	6.6	12.0	25	263.6
Noogseed	6.0	16.5	26	368.6
Horsebeans	12.5	24.5	15	215.8
Haricotbeans	12.0	23.0	28	238.8
Lentils	8.0	17.0	27	218.8
Fenugruk	7.5	15.5	25	235.8
Pepper	5.3	11.2	52	293.8
Potatoes	66.2	120.0	10	405.8
Onions	49.1	100.0	10	406.8

SOURCES: U.S. Department of Interior, Bureau of Reclamation, Land and Water Resources of the Blue Nile Basin of Ethiopia (Washington, D.C.: U.S.D.I., 1964), pp. 186-194 and pp. 232-233; National Crop Improvement Committee, Results of the National Crop Trials 1972 (Addis Ababa: I.A.R.); Imperial Ethiopian Government, Ministry of Agriculture, Extension Service and F.A.O., "Freedom from Hunger Campaign: Fertilizer Demonstrations Program 1969/70" (Unpublished Report, Addis Ababa, n.d.).

$$- X_{4t} \leq - X_{4t-1} \quad (1.08)$$

$$- X_{5t} \leq - X_{5t-1} \quad (1.09)$$

$$- X_{6t} \leq - X_{6t-1} \quad (1.09)$$

$$- X_{7t} \leq - X_{7t-1} \quad (1.04)$$

$$- X_{8t} \leq - X_{8t-1} \quad (1.05)$$

$$- X_{9t} \leq - X_{9t-1} \quad (0)$$

$$X_{10t} \leq X_{10t-1} \quad (1.65)$$

$$- X_{11t} \leq - X_{11t-1} \quad (0)$$

$$X_{12t} \leq X_{12t-1} \quad (1.34)$$

$$X_{13t} \leq X_{13t-1} \quad (1.91)$$

$$X_{14t} \leq X_{14t-1} \quad (1.35)$$

and

$$X_{it} \geq 0.$$

where N = number of crop enterprises.

R_{it} = net return per hectare of crop i at year t,

X_{it} = hectares of crop i at year t,

X_{1t} = barley at year t,

X_{2t} = maize at year t,

X_{3t} = sorghum at year t,

X_{4t} = teff at year t,

X_{5t} = wheat at year t,

X_{6t} = linseed at year t,

X_{7t} = noogseed at year t,

X_{8t} = horsebeans at year t,

X_{9t} = haricotbeans at year t,

X_{10t} = lentils at year t,

X_{11t} = fenugreek at year t,

X_{12t} = pepper at year t,

X_{13t} = potatoes at year t,

X_{14t} = onions at year t.

The land and commodity flexibility coefficients were determined exogenously. The land flexibility coefficient was based on the assumption made in the study regarding the rate of irrigation development in the project area. It is to be recalled that in the project plan, 10 percent of

the total project land was anticipated to be developed each year. Therefore, starting with 589 hectares of irrigated land in the first year, the total area of irrigated land will be increased by equal increments each year until the entire project area of 5,890 hectares is brought under irrigation in the tenth year. The land flexibility constraint, therefore, is designed to reflect this situation. The commodity flexibility restraints, on the other hand, are based on the estimated rates of change in the consumption needs of the population of the project area. The coefficients basically reflect the rate at which the staple commodities (primarily cereal grains) must be expanded annually in order to meet the nutritional requirements of the population of the project areas. The initial consumption requirements of the population of the project areas were determined on the basis of estimated least-cost diets and average national daily per capita consumption requirements suggested by other studies.[1] Appropriate lower flexibility restraints were placed on the staple grains, while upper flexibility restraints were imposed on three specific commodities, namely, pepper, potatoes, and onions to ensure that these commodities were not unduly expanded. A computer model was subsequently developed and utilized to solve the

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[1] Carl F. Miller, _et al_., _Systems Analysis Methods for Ethiopian Agriculture_; Imperial Ethiopian Government, Interdepartmental Committee on Nutrition for National Defence, _Ethiopian Nutrition Survey_ (Addis Ababa: I.E.G., September, 1959).

ten year recursive system in one run. A summary of the computer printout depicting the optimal ten year crop mix and land allocation plan for Strategy I is presented in Appendix D.1.

The annual associated costs and the annual direct project benefits under the present farm management strategy were then calculated based on the optimal solution obtained from the recursive model. Table 6.5 presents the annual associated costs and annual direct benefits of the project under Strategy I. It is clear from this table that both associated costs and benefits increase during the first ten years as the project expands and remain constant for the subsequent 30 years, once the irrigation program reaches a stable leve.

2. <u>Strategy II - Semi-Mechanized Operation</u>

This strategy is based on the assumption that plowing, threshing and on-farm transportation would be mechanized while all other operations will be performed manually. (See Appendix C.4 for machinery performance coefficients.) This strategy, of course, provides certain definite advantages. It is still labor intensive; machine power only replaces animal power without significantly affecting labor employment. It also offers the advantage of more timely operation and affords more convenience and ease of operation. It is certainly a strategy that seems to have considerable potential for streamlining Ethiopia's agricultural

TABLE 6.5

ESTIMATED ANNUAL ASSOCIATED COSTS AND ANNUAL DIRECT BENEFITS

STRATEGY I: ANIMAL POWERED OPERATION - MEGECH RIVER PROJECT

Planning Year	Annual Associated Costs	Annual Gross Direct Benefits	Annual Gross Direct Benefits Less Associated Costs	Annual Net Project Benefits
		In '000 of 1970 Eth. Dollars		
0	--	--	--	-2,226.10
1	151.79	250.71	98.92	-2,121.08
2	300.10	571.02	270.85	-1,722.04
3	451.95	919.13	467.18	-1,447.06
4	600.97	1,312.34	711.37	-1,139.76
5	748.82	1,732.33	983.51	- 790.37
6	897.84	2,205.19	1,307.34	- 388.29
7	1,046.86	2,716.52	1,669.66	50.27
8	1,195.88	3,275.19	2,079.31	530.10
9	1,344.89	3,882.50	2,537.60	1,068.76
10	1,493.91	4,544.63	3,050.72	1,085.81
11	1,493.91	4,544.63	3,050.72	2,317.89
12	1,493.91	4,544.63	3,050.72	2,316.47
13	1,493.91	4,544.63	3,050.72	2,312.23
14	1,493.91	4,544.63	3,050.72	2,313.65
15	1,493.91	4,544.63	3,050.72	2,310.82
16	1,493.91	4,544.63	3,050.72	2,309.41
17	1,493.91	4,544.63	3,050.72	2,306.58
18	1,493.91	4,544.63	3,050.72	2,300.93
19	1,493.91	4,544.63	3,050.72	2,298.10
20	1,493.91	4,544.63	3,050.72	2,299.51
21	1,493.91	4,544.63	3,050.72	2,296.69
22	1,493.91	4,544.63	3,050.72	2,295.27

TABLE 6.5 (CONTINUED)

Planning Year	Annual Associated Costs	Annual Gross Direct Benefits	Annual Gross Direct Benefits Less Associated Costs	Annual Net Project Benefits
		In '000 of 1970 Eth. Dollars		
23	1,493.91	4,544.63	3,050.72	2,298.01
24	1,493.91	4,544.63	3,050.72	2,306.66
25	1,483.91	4,544.63	3,050.72	2,309.26
26	1,493.91	4,544.63	3,050.72	2,310.68
27	1,493.91	4,544.63	3,050.72	2,312.22
28	1,493.91	4,544.63	3,050.72	2,315.05
29	1,493.91	4,544.63	3,050.72	2,316.33
30	1,493.91	4,544.63	3,050.72	2,319.16
31	1,493.91	4,544.63	3,050.72	2,322.13
32	1,493.91	4,544.63	3,050.72	2,325.13
33	1,493.91	4,544.63	3,050.72	3,325.11
34	1,493.91	4,544.63	3,050.72	2,326.37
35	1,493.91	4,544.63	3,050.72	2,330.61
36	1,493.91	4,544.63	3,050.72	2,322.02
37	1,493.91	4,544.63	3,050.72	2,332.43
38	1,493.91	4,544.63	3,050.72	2,333.85
39	1,493.91	4,544.63	3,050.72	2,334.26
40	1,493.91	4,544.63	3,050.72	2,336.49

SOURCE: Computed by author.

production system.

But this strategy also has some serious drawbacks compared to Strategy I. It requires considerable foreign exchange expenditure both to purchase the machinery and compliments and to obtain replacements, spare parts, fuel, oil and grease on an ongoing basis. This strategy would also require skilled workers such as tractor operators, mechanics and machine shop operators to operate and maintain the farm machinery and equipment efficiently.

These drawbacks do not seem hard to circumvent. Part of the output of the project can be exported to pay for the needed imports of machinery, equipment and supplies. The foreign exchange cost of importing machinery can also be met by rearranging national priorities. For instance, more machinery can be imported by diverting foreign exchange expenditure from private automobiles to the purchase of farm machinery. The same goes for the consumption of fuel, oil, and grease as well as the purchase of spare parts. As far as skilled farm workers are concerned, there are presently a sufficient number of technical training institutions in the country to supply the modest number of skilled technicians required to make this strategy feasible.

The crops, yields, prices and cost of production per hectare for each of the crops considered under Strategy II are shown in Table 6.6. As in Strategy I, a ten year recursive model was utilized to determine the optimum crop mix under this strategy. Except for changes in the net return

TABLE 6.6

CROP YIELDS, IMPUTED FARM GATE PRICES AND ESTIMATED COST OF PRODUCTION PER HECTARE - STRATEGY II: SEMI-MECHANIZED OPERATION - MEGECH RIVER PROJECT

Type of Crop	Average Existing Yields 100 kg/ha	Expected Irrigated Yields After 10 Years 100 kg/ha	Imputed Farm Gate Prices $/100 kg	Estimated Cost of Production $/ha
			In 1970 Eth. Dollars	
Barley	12.7	28.4	18	230.7
Maize	27.5	63.2	81	258.5
Sorghum	25.5	58.3	20	253.8
Teff	11.6	22.6	28	384.3
Wheat	11.6	25.2	24	375.6
Linseed	6.6	15.2	25	265.6
Noogseed	6.0	19.0	26	371.0
Horsebeans	12.5	29.5	15	226.5
Haricotbeans	12.0	26.0	28	248.6
Lentils	8.0	21.2	27	235.7
Fenugreek	7.5	18.0	25	245.4
Pepper	5.3	13.0	52	302.5
Potatoes	66.2	156.4	10	425.0
Onions	49.1	124.1	10	424.0

SOURCES: C.F. Miller, *et al*., *Systems Analysis Methods for Ethiopian Agriculture* (Menlo Park, California: S.R.I., 1968); M.E. Quenemoen, *Potential Returns from Commercial Farming Systems in Three Areas of Ethiopia* (Dire Dawa, Ethiopia: Haile Selassie I University, College of Agriculture, 1968); National Crop Improvement Committee, *Results of the National Crop Trials 1972* (Addis Ababa: I.A.R.); U.S. Department of Interior, Bureau of Reclamation, *Land and Water Resources of the Blue Nile Basin of Ethiopia* (Washington, D.C.: U.S.D.I., 1964).

per hectare or the objective function, Strategy II uses basically the same model as Strategy I. The solution to the model obtained from the computer printout is summarized in Appendix D.2. The optimal crop mix and land allocation plan suggested by the model were subsequently used as a basis to calculate the annual associated costs and annual gross direct benefits. These figures are outlined in Table 6.7.

3. Strategy III - Fully Mechanized Agriculture

This strategy should be self-explanatory. It is based on the assumption that the agricultural operation in the project area is fully mechanized. It assumes that the entire operation from initial plowing and seedbed preparation to harvesting and storage of the farm product is accomplished by fully mechanized units.

The main advantage of this strategy, of course, is a timely, efficient and convenient operation. But it has far reaching implications with regard to foreign exchange requirements and labor employment.

The inclusion of this strategy as a limiting case among the range of viable farm management strategies for the project area is, however, very useful from the standpoint of investigating whether or not the social gains in production efficiency flowing from mechanized agriculture would be sufficient to offset any associated losses in employment and foreign exchange. It is with this understand-

TABLE 6.7

ESTIMATED ANNUAL ASSOCIATED COSTS AND ANNUAL DIRECT BENEFITS
STRATEGY II: SEMI-MECHANIZED OPERATION - MEGECH RIVER PROJECT

Planning Year	Annual Associated Costs	Annual Gross Direct Benefits	Annual Gross Direct Benefits Less Associated Costs	Annual Net Project Benefits
		In '000 of 1970 Eth. Dollars		
0	--	--	--	-2,226.10
1	163.76	236.95	123.17	-2,096.77
2	312.19	703.78	391.60	-1,601.29
3	473.16	1,177.28	704.13	-1,201.11
4	621.58	1,680.22	1,058.63	- 792.49
5	770.01	2,232.22	1,462.21	- 311.67
6	918.44	2,836.10	1,917.66	221.02
7	1,066.87	3,493.20	2,426.33	806.94
8	1,215.30	4,212.66	2,997.36	1,448.15
9	1,363.72	4,994.93	3,631.20	2,162.36
10	1,512.15	5,840.67	4,328.51	3,083.61
11	1,512.15	5,840.67	4,328.51	3,595.66
12	1,512.15	5,840.67	4,328.51	3,584.27
13	1,512.15	5,840.67	4,328.51	3,590.02
14	1,512.15	5,840.67	4,328.51	3,591.44
15	1,512.15	5,840.67	4,328.51	3,588.61
16	1,512.15	5,840.67	4,328.51	3,587.20
17	1,512.15	5,840.67	4,328.51	3,584.37
18	1,512.15	5,840.67	4,328.51	3,578.72
19	1,512.15	5,840.67	4,328.51	3,575.89
20	1,512.15	5,840.67	4,328.51	3,577.30
21	1,512.15	5,840.67	4,328.51	3,584.48

TABLE 6.7 (CONTINUED)

Planning Year	Annual Associated Costs	Annual Gross Direct Benefits	Annual Gross Direct Benefits Less Associated Costs	Annual Net Project Benefits
		In '000 of 1970 Eth. Dollars		
22	1,512.15	5,840.67	4,328.51	3,573.06
23	1,512.15	5,840.67	4,328.51	3,575.80
24	1,512.15	5,840.67	4,328.51	3,584.45
25	1,512.15	5,840.67	4,328.51	3,587.06
26	1,512.15	5,840.67	4,328.51	3,588.47
27	1,512.15	5,840.67	4,328.51	3,590.01
28	1,512.15	5,840.67	4,328.51	3,592.84
29	1,512.15	5,840.67	4,328.51	3,594.12
30	1,512.15	5,840.67	4,328.51	3,596.95
31	1,512.15	5,840.67	4,328.51	3,599.92
32	1,512.15	5,840.67	4,328.51	3,602.60
33	1,512.15	5,840.67	4,328.51	3,601.90
34	1,512.15	5,840.67	4,328.51	3,604.16
35	1,512.15	5,840.67	4,328.51	3,608.40
36	1,512.15	5,840.67	4,328.51	3,609.81
37	1,512.15	5,840.67	4,328.51	3,610.23
38	1,512.15	5,840.67	4,328.51	3,611.64
39	1,512.15	5,840.67	4,328.51	3,612.05
40	1,512.15	5,840.67	4,328.51	3,614.28

SOURCE: Computed by author.

ing that this strategy is considered.

The crops, yields, prices and per hectare production costs considered under this strategy are shown in Table 6.8. As in the preceding two strategies, the optimum crop mix and land allocation plan for this strategy were derived from the optimal solution of a ten year recursive model. Again, except for differences in net return per hectare which alter the parameters of the objective function, the elements of this model are similar to those used in the preceding two strategies. The optimal solution of the model is summarized in Appendix D.3. The annual associated costs and annual direct benefits were then calculated based on the optimal land allocation plan and the corresponding figures are itemized in Table 6.9.

Economic Analysis of the Kesem River Project

The South Kesem River area, in the Awash River Basin, forms the focus of the second area of investigation. The principal reason for including this area in the present study is to determine whether the lowlands of Ethiopia offer economically viable opportunities for increasing food-grain production, expanding employment and enhancing the general welfare of the inhabitants of the lowland areas.

The proposed scheme envisages use of the waters of the Kesem River to irrigate about 5,650 hectares of land

TABLE 6.8

CROP YIELDS, IMPUTED FARM GATE PRICES AND ESTIMATED COST OF PRODUCTION PER HECTARE - STRATEGY III: FULLY MECHANIZED OPERATION - MEGECH RIVER PROJECT

Type of Crop	Average Existing Yields 100 kg/ha	Expected Irrigated Yields After 10 Years 100 kg/ha	Imputed Farm Gate Prices $/100 kg	Estimated Cost of Production $/ha
			In 1970 Eth. Dollars	
Barley	12.7	29.4	18	[illegible]
Maize	27.5	66.3	18	285.2
Sorghum	25.5	60.2	20	287.3
Teff	11.6	22.6	28	385.5
Wheat	11.6	27.2	24	360.8
Linseed	6.6	15.2	25	278.9
Noogseed	6.0	19.0	26	378.2
Horsebeans	12.5	31.0	15	246.5
Haricotbeans	12.0	27.0	28	278.6
Lentils	8.0	21.2	27	235.7
Fenugreek	7.5	18.0	25	255.3
Pepper	5.3	13.0	52	315.3
Potatoes	66.2	200.0	10	485.0
Onions	49.1	160.0	10	478.8

SOURCES: Imperial Ethiopian Government, Ministry of Agriculture, Extension Service, and F.A.O., "Freedom from Hunger Campaign: Fertilizer Demonstration Programs, 1967/68, 1968/69, 1969/70 and 1970/71" (Addis Ababa: Unpublished reports, n.d.); Institute of Agricultural Research, Progress Report for the Period April, 1970 to March, 1971 (Bako Research Station, 1971); Institute of Agricultural Research, Progress Report for the Period April, 1969 to March, 1970 Holeta Geent Research Station, May, 1970); National Crop Improvement Committee, Results of the National Crop Trials 1972 (Addis Ababa: I.A.R., 1974); C.F. Miller, et al., Systems Analysis Methods for Ethiopian Agriculture (Menlo Park: S.R.I., 1968).

TABLE 6.9

ESTIMATED ANNUAL ASSOCIATED COSTS AND ANNUAL DIRECT BENEFITS
STRATEGY III: FULLY MECHANIZED OPERATION - MEGECH RIVER PROJECT

Planning Year	Annual Associated Costs	Annual Gross Direct Benefits	Annual Gross Direct Benefits Less Associated Costs	Annual Net Project Benefits
		In '000 of 1970 Eth. Dollars		
0	--	--	--	-2,226.10
1	246.06	347.74	101.67	-2,118.28
2	493.74	833.08	339.35	-1,653.54
3	739.13	1,342.42	603.28	-1,310.95
4	986.58	1,918.46	931.87	- 919.25
5	1,234.26	2,553.31	1,319.05	- 454.83
6	1,481.93	3,247.14	1,765.21	68.57
7	1,728.15	3,987.50	2,259.35	639.95
8	1,975.83	4,808.26	2,832.43	1,283.22
9	2,223.50	5,699.24	3,475.74	2,006.89
10	2,458.98	6,650.83	4,191.85	2,946.94
11	2,458.98	6,650.83	4,191.85	3,459.01
12	2,458.98	6,650.83	4,191.85	3,457.60
13	2,458.98	6,650.83	4,191.85	3,453.36
14	2,458.98	6,650.83	4,191.85	3,545.77
15	2,458.98	6,650.83	4,191.85	3,451.94
16	2,458.98	6,650.83	4,191.85	3,450.53
17	2,458.98	6,650.83	4,191.85	3,447.70
18	2,458.98	6,650.83	4,191.85	3,442.05
19	2,458.98	6,650.83	4,191.85	3,439.22
20	2,458.98	6,650.83	4,191.85	3,440.64
21	2,458.98	6,650.83	4,191.85	3,437.81

TABLE 6.9 (CONTINUED)

Planning Year	Annual Associated Costs	Annual Gross Direct Benefits	Annual Gross Direct Benefits Less Associated Costs	Annual Net Project Benefits
		In '000 of 1970 Eth. Dollars		
22	2,458.98	6,650.83	4,191.85	3,536.40
23	2,458.98	6,650.83	4,191.85	3,439.14
24	2,458.98	6,650.83	4,191.85	3,447.78
25	2,458.98	6,650.83	4,191.85	3,450.39
26	2,458.98	6,650.83	4,191.85	3,451.80
27	2,458.98	6,650.83	4,191.85	3,453.34
28	2,458.98	6,650.83	4,191.85	3,450.17
29	2,458.98	6,650.83	4,191.85	3,457.46
30	2,458.98	6,650.83	4,191.85	3,460.28
31	2,458.98	6,650.83	4,191.85	3,463.25
32	2,458.98	6,650.83	4,191.85	3,465.94
33	2,458.98	6,650.83	4,191.85	3,465.23
34	2,458.98	6,650.83	4,191.85	3,467.49
35	2,458.98	6,650.83	4,191.85	3,471.73
36	2,458.98	6,650.83	4,191.85	3,473.15
37	2,458.98	6,650.83	4,191.85	3,473.56
38	2,458.98	6,650.83	4,191.85	3,474.97
39	2,458.98	6,650.83	4,191.85	3,475.39
40	2,458.98	6,650.83	4,191.85	3,477.62

SOURCE: Computed by author.

and also to provide clean water supplies for domestic and stock use. The project plan calls for the direct pumping of the required quantity of water from the Kesem River using diesel water pumps. Although the possibility of using electric water pumps by drawing electric power from the Koka hydro-interconnected grid exists, its feasibility has not been investigated because of the unavailability of reliable cost estimates at the time this study was done. Accordingly, the cost and benefit estimates of Kesem Project, which are outlined below, are based on a diesel powered pump irrigation system.

Project Costs

Among the main construction features considered in estimating the project cost are the pumping plant, main canals, distribution system, access and farm roads, housing for employees and settlers, service facilities including a school, a clinic, a community center, a workshop, a machinery shed and storage facilities. The project is intended to be phased in over a ten year period, and the economic life of the project is set at 40 years. The required annual project outlays, which encompass the capital investment outlay, interest charges during construction, operation, maintenance, and replacement costs and land development costs, have been itemized in Table 6.10.

Unlike the Megech River Project, the analysis of the Kesem Project did not include various alternatives.

TABLE 6.10

ESTIMATED PROJECT COSTS, KESEM RIVER PROJECT

Planning Year	Capital Investment	Interest During Construction	Operation and Maintenance Cost	Replacement Cost	Land Develop-ment Cost	Total Annual Project Cost
			In '000 of 1970 Eth. Dollars			
0	2,351.20	67.56	--	--	--	2,418.76
1	1,261.12	63.06	66.91	--	67.24	1,458.32
2	1,080.96	54.05	133.82	--	67.24	1,336.06
3	990.88	49.54	200.72	--	67.24	1,308.38
4	900.80	45.04	267.63	13.61	67.24	1,294.32
5	810.72	40.54	334.54	14.87	67.24	1,267.91
6	720.64	36.03	401.45	17.32	67.24	1,242.68
7	630.56	31.53	468.53	23.52	67.24	1,221.21
8	540.48	27.02	535.27	26.75	67.24	1,196.76
9	450.40	22.52	602.17	27.32	67.24	1,169.65
10	270.27	13.51	669.08	28.33	67.24	1,048.42
11	--	--	669.08	31.12	--	700.20
12	--	--	669.08	29.75	--	698.83
13	--	--	669.08	33.72	--	702.80
14	--	--	669.08	35.24	--	704.32
15	--	--	669.08	38.57	--	707.65
16	--	--	669.08	39.84	--	708.92
17	--	--	669.08	41.53	--	710.61
18	--	--	669.08	45.78	--	714.86
19	--	--	669.08	48.92	--	718.00
20	--	--	669.08	51.62	--	720.70
21	--	--	669.08	53.42	--	722.50

TABLE 6.10 (CONTINUED)

Planning Year	Capital Investment	Interest During Construction	Operation and Maintenance Cost	Replacement Cost	Land Develop-ment Cost	Total Annual Project Cost
			In '000 of 1970 Eth. Dollars			
22	--	--	669.08	54.65	--	723.73
23	--	--	669.08	52.38	--	721.46
24	--	--	669.08	53.21	--	722.29
25	--	--	669.08	50.37	--	719.45
26	--	--	669.08	47.34	--	716.42
27	--	--	669.08	46.73	--	715.81
28	--	--	669.08	45.13	--	714.21
29	--	--	669.08	43.02	--	712.10
30	--	--	669.08	39.33	--	708.41
31	--	--	669.08	37.34	--	706.32
32	--	--	669.08	33.42	--	702.50
33	--	--	669.08	29.21	--	698.29
34	--	--	669.08	27.31	--	696.39
35	--	--	669.08	25.24	--	694.32
36	--	--	669.08	23.78	--	692.86
37	--	--	669.08	21.98	--	691.06
38	--	--	669.08	19.48	--	688.56
39	--	--	669.08	16.36	--	685.44
40	--	--	669.08	15.78	--	684.86

SOURCE: Food and Agriculture Organization of the United Nations, Survey of the Awash River Basin, Vol. I: General Report and Vol. V: Irrigation and Water Planning (Rome: F.A.O., 1965).

The reasons are inherent in the nature of the Kesem River Project area itself. The proposed project area is presently used by nomadic pastoralists as part of their traditional grazing area within the broader range lands of the Middle and Lower Awash Valley. The carrying capacity of the area is extremely low, being estimated at between 0.05 to 0.25 head of cattle per hectare.[1] The economic value of the area in its present use is therefore quite negligible.

In view of the extreme scarcity of water, prospects for the future development of the area "without" the project seem to be practically nil. The best that can be expected in the absence of the project is an indefinite continuation of existing grazing activity. Furthermore, alternative forms of farm organization "with" the project do not seem to be viable under conditions prevailing in the Kesem Project area. Preliminary investigations and the experience of commercial farmers in the Awash Valley clearly indicate that a semi-mechanized technology rather than animal powered or fully mechanized technology seems to be the most suitable and appropriate for the area. Accordingly, the economic analysis of the Kesem River Project was based on the assumption of a semi-mechanized technology. As the term is used in this study, the semi-mechanized

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[1] C.F. Miller, et al., Systems Analysis Methods for Ethiopian Agriculture, p. 303.

technology involves the use of mechanized units for plowing and seedbed preparation as well as threshing and transportation.

Associated Costs

In order to estimate the associated costs of the Kesem Project consistent with the assumed farm technology, a ten year recursive program incorporating the twelve different crops shown in Table 6.11 and the relevant land and commodity flexibility constraints was employed. The following model was used to derive the optimal crop mix and land allocation plan.

$$\text{Maximize } Z_t = \sum_{i=1}^{N} R_{it} X_{it}, \quad N=12, \quad t=1,\ldots,T$$

subject to:

$$X_{1t} + X_{2t} + \ldots + X_{12t} \leq 5650\ (0.10)(t)$$

$$- X_{1t} \leq - X_{1t-1}\ (0)$$

$$- X_{2t} \leq - X_{2t-1}\ (0)$$

$$X_{3t} \leq X_{3t-1}\ (1.50)$$

TABLE 6.11

CROP YIELDS, IMPUTED FARM GATE PRICES AND ESTIMATED COST OF PRODUCTION, KESEM PROJECT

Type of Crop	Average Existing Yields 100 kg/ha	Expected Irrigated Yields After 10 Years 100 kg/ha	Imputed Farm Gate Prices $/100 kg	Estimated Cost of Production $/ha
			In 1970 Eth. Dollars	
Barley	18	29	17	299
Casterseeds	16	24	25	362
Cotton	14	23	60	529
Groundnuts	31	49	32	501
Maize	28	68	16	518
Onions	49	75	8	284
Potatoes	68	88	8	407
Safflower	15	26	21	379
Sorghum	22	55	16	433
Soybeans	13	22	18	328
Teff	16	24	25	332
Wheat	12	25	22	269

SOURCES: Food and Agriculture Organization of the United Nations, Survey of the Awash River Basin, Vol. 1: General Report, Vol. II: Soils and Agronomy; Vol. V: Irrigation and Water Planning (Rome: F.A.O., 1965); John Asfaw, "Production Cost Budgets for an Arable Farm in the Bishoftu Area: The Present System of Peasant Farming Versus an Assumed Improved Input System" (Unpublished Report, Addis Ababa, Stanford Research Institute, February, 1968); Solomon Bekure and Feyissa Demie, "Cost and Returns Study of Teff and Wheat in 1970 at the Debre Zeit Experiment Station, A Progress Report" (Unpublished Report, Dire Dawa, College of Agriculture, n.d.); C.F. Miller, et al., Systems Analysis Methods for Ethiopian Agriculture (Menlo Park, California: S.R.I., 1968); National Crop Improvement Committee, Results of the National Crop Trials 1972 (Addis Ababa: I.A.R., 1974); M.E. Quenemoen, Potential Returns from Commercial Farming Systems in Three Areas of Ethiopia (Dire Dawa: H.S.I.U., College of Agriculture, 1968).

$$X_{4t} \leq X_{4t-1} \quad (1.35)$$

$$- X_{5t} \leq - X_{5t-1} \quad (1.07)$$

$$X_{6t} \leq X_{6t-1} \quad (1.85)$$

$$X_{7t} \leq X_{7t-1} \quad (1.95)$$

$$- X_{8t} \leq - X_{8t-1} \quad (0)$$

$$- X_{9t} \leq - X_{9t-1} \quad (1.07)$$

$$- X_{10t} \leq - X_{10t-1} \quad (0)$$

$$- X_{11t} \leq - X_{11t-1} \quad (0)$$

$$- X_{12t} \leq - X_{12t-1} \quad (1.030)$$

and

$$X_{it} \geq 0.$$

where N = the number of crop enterprises considered,

R_{it} = net return per hectare of crop i at year t,

X_{it} = hectares of crop i at year t,

X_{1t} = barley at year t,

X_{2t} = casterseeds at year t,

X_{3t} = cotton at year t,

X_{4t} = groundnuts at year t,

X_{5t} = maize at year t,

X_{6t} = onions at year t,

X_{7t} = potatoes at year t,

X_{8t} = safflower at year t,

X_{9t} = sorghum at year t,

X_{10t} = soybeans at year t,

X_{11t} = teff at year t,

X_{12t} = wheat at year t.

As for the Megech Project, the land and commodity flexibility coefficients of the Kesem Project were determined exogenously. The land flexibility coefficient is designed to reflect the annual rate at which land development should proceed so that the entire project area can be developed in ten years. The commodity flexibility coefficients are set at levels that will ensure that at least some minimum quantity of the staple commodities will be produced and non-essential commodities cannot be expanded without any restrictions. In the latter case, maximum constraints are imposed on certain cash crops so that their rate of expansion cannot be larger than market limitations and traditional farmers' reluctance to expand into such crops would allow. It should be emphasized that these

restraints are partly based on the author's assessment of historical factors that have shaped the pattern of agricultural production in Ethiopia and the likely influences of these factors on production patterns in the project area. The cropping patterns suggested by the optimal solution of the program are summarized in Appendix D.4.

The optimal crop mix and land allocation plan derived from the foregoing model were subsequently used in the estimation of the associated costs of the Kesem Project. The following formula was employed to estimate the annual associated costs.

$$A_t = \sum_{i=1}^{N} C_{it}H_{it}, \quad t=1,\ldots,T$$

where A_t = associated cost at year t,

C_{it} = per hectare production cost of crop i at year t,

H_{it} = number of hectares allocated to crop i at year t,

N = the number of crops in the optimal plan in year t,

T = the planning horizon.

Annual associated costs were estimated for each year of the entire planning horizon and the estimates obtained are itemized in Table 6.12.

TABLE 6.12

ESTIMATED ANNUAL ASSOCIATED COSTS AND ANNUAL DIRECT BENEFITS

KESEM RIVER PROJECT

Planning Year	Annual Associated Costs	Annual Gross Direct Benefits	Annual Gross Direct Benefits Less Associated Costs	Annual Net Project Benefits
		In '000 of 1970 Eth. Dollars		
0	--	--	--	-2,418.76
1	282.84	466.35	183.51	-1,274.82
2	565.69	1,004.29	438.60	- 897.11
3	848.53	1,621.37	772.83	- 535.54
4	1,131.38	2,327.25	1,195.88	- 98.44
5	1,414.22	3,131.27	1,717.04	449.14
6	1,697.07	4,045.98	2,348.92	1,106.24
7	2,269.66	5,076.47	2,806.81	1,564.14
8	2,262.76	6,254.41	3,991.65	2,794.89
9	2,545.36	7,575.94	5,030.58	3,860.93
10	2,828.45	9,063.39	6,234.95	5,186.52
11	2,828.45	9,063.39	6,234.95	5,534.74
12	2,828.45	9,063.39	6,234.95	5,536.11
13	2,828.45	9,063.39	6,234.95	5,532.15
14	2,828.45	9,063.39	6,234.95	5,530.63
15	2,828.45	9,063.39	6,234.95	5,527.30
16	2,828.45	9,063.39	6,234.95	5,526.03
17	2,828.45	9,063.39	6,234.95	5,524.34
18	2,828.45	9,063.39	6,234.95	5,520.09
19	2,828.45	9,063.39	6,234.95	5,516.94
20	2,828.45	9,063.39	6,234.95	5,514.25
21	2,828.45	9,063.39	6,234.95	5,512.44

TABLE 6.12 (CONTINUED)

Planning Year	Annual Associated Costs	Annual Gross Direct Benefits	Annual Gross Direct Benefits Less Associated Costs	Annual Net Project Benefits
		In '000 of 1970 Eth. Dollars		
22	2,828.45	9,063.39	6,234.95	5,511.22
23	2,828.45	9,063.39	6,234.95	5,513.49
24	2,828.45	9,063.39	6,234.95	5,512.66
25	2,828.45	9,063.39	6,234.95	5,515.49
26	2,828.45	9,063.39	6,234.95	5,518.53
27	2,828.45	9,063.39	6,234.95	5,519.14
28	2,828.45	9,063.39	6,234.95	5,520.74
29	2,828.45	9,063.39	6,234.95	5,522.84
30	2,828.45	9,063.39	6,234.95	5,526.54
31	2,828.45	9,063.39	6,234.95	5,528.63
32	2,828.45	9,063.39	6,234.95	5,532.44
33	2,828.45	9,063.39	6,234.95	5,536.66
34	2,828.45	9,063.39	6,234.95	5,538.55
35	2,828.45	9,063.39	6,234.95	5,540.62
36	2,828.45	9,063.39	6,234.95	5,542.09
37	2,828.45	9,063.39	6,234.95	5,543.88
38	2,828.45	9,063.39	6,234.95	5,546.39
39	2,828.45	9,063.39	6,234.95	5,549.51
40	2,828.45	9,063.39	6,234.95	5,550.08

SOURCE: Computed by author.

Gross Direct Benefits

Like the annual associated costs, the gross annual direct benefits of the Kesem Project are also calculated on the basis of the optimal crop mix and land allocation plan derived from the recursive program. The following formula was employed in making the benefit estimates.

$$B_t = \sum_{i=1}^{N} P_i Y_{it} H_{it}, \quad t=1,\ldots,T$$

where B_t = the gross annual direct benefit at year t,

P_i = the unit price of crop i in 1970 dollars,

Y_{it} = the yield level of crop i at year t,

H_{it} = the number of hectares allocated to crop i in the optimal plan of year t,

N = the number of crop enterprises in the optimal crop mix,

T = the planning horizon.

The estimated annual benefits extending over the entire economic life of the project are detailed in Table 6.12.

In conclusion, this chapter has described the empirical procedures and has outlined the data employed in the economic analysis of the proposed Megech and Kesem River Projects. The following chapter will attempt to summarize the results of the empirical analysis.

CHAPTER VII

RESULTS OF EMPIRICAL ANALYSIS AND POLICY IMPLICATIONS

The empirical analysis described in the preceding chapter was conducted in an effort to answer some of the fundamental questions raised in this study. The first question the analysis sought to answer was whether the two projects proposed in this study were economically and financially feasible. Secondly, it attempted to determine whether the kind of public investment program suggested in this study shows a good prospect of materially contributing to the expansion of food production and employment in Ethiopia. This chapter summarizes the important results of the empirical analysis. In particular, it presents the economic and financial feasibility of the proposed projects and their likely impact on food production and employment. It also outlines the important policy implications of the study.

Results of Economic Analysis

The principal purpose of economic feasibility analysis is to determine whether the overall social benefits of a project outweigh the total social costs. An equally import-

ant aspect of economic feasibility analysis is the ranking of various projects according to a certain widely accepted criterion or set of criteria.

Depending on specific circumstances, project selection criteria can be chosen from a wide range of economic desirability indicators. Which criterion or set of criteria are chosen often depends, among other things, on the specific factors of production that are considered most limiting. However, unless the projects being ranked are fairly well standardized with respect to capital requirements, planning horizon and possible reinvestment of earnings, different criteria may give different rankings and hence may lead to different conclusions.[1]

In this study, both projects have reasonably close capital requirements, and their planning horizons and reinvestment patterns are essentially the same. Hence, assuming that investment capital is the most limiting factor in Ethiopia, the following investment criteria were selected for ranking the projects:

1. The present discounted value of net benefit,
2. The benefit cost ratio, and
3. The internal rate of return.

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[1] Otto Eckstein, Water Resource Development: The Economics of Project Evaluation, pp. 53-69; and E.J. Mishan, Cost-Benefit Analysis, pp. 181-226.

The Present Discounted Value of Net Benefits (PVNB)

This criterion can be used both for determining the optimum scale of a single project and for ranking several projects that compete for a given level of capital outlay. This criterion was applied to the two projects analyzed in this study and the result is shown in Table 7.1. As can be noted from the table, three discount rates were used. According to the results obtained, the Kesem River Project seems to have a clear edge over the Megech River Project under comparable levels of technology. The Kesem River Project, under semi-mechanized technology and at a discount rate of 10 percent, shows a present discounted net benefit of E $22.1 million, while under corresponding technology and discount rate, the Megech Project has a present discounted net benefit of E $8.9 million. At 15 percent, the present discounted net benefits decline to E $8.6 million and E $1.2 million, respectively. It is interesting to note that under the animal powered technology, the Megech River Project ceases to be economically feasible at discount rates higher than 11 percent.

The Benefit-Cost Ratio

The benefit-cost ratio criterion attempts to compare and rank projects on the basis of their benefit-cost ratios. According to this criterion, projects with ratios greater than one are economically feasible and hence eligible for construction. Of the eligible projects, those with rela-

TABLE 7.1

PRESENT VALUE OF NET BENEFITS DISCOUNTED
AT 10 PERCENT, 12 PERCENT AND 15 PERCENT
MEGECH AND KESEM PROJECTS

Projects	Present Discounted Value of Net Benefits 10%	12%	15%
	(In '000 of 1970 Eth. Dollars)		
Megech River Project			
Strategy I - Animal Powered Operation	1,616.31	-741.87	-2,882.16
Strategy II - Semi-Mechanized Operation	8,864.33	5,000.52	1,224.17
Strategy III - Fully Mechanized Operation	7,911.84	4,186.96	598.52
Kesem Project			
Semi-Mechanized Operation	22,102.23	13,960.98	8,608.93

SOURCE: Computed by author.

tively higher ratios are preferred to those with lower ratios, other things being equal.

When applying this criterion to the proposed projects, a result consistent with that of the present value criterion discussed earlier was obtained. The benefit-cost ratio criterion also ranked the Kesem Project first and the Megech Project second (Table 7.2). Under the semi-mechanized technology and 10 percent discount rate, the Megech Project had a benefit-cost ratio of 1.6, while the Kesem Project showed a markedly higher ratio of 2.7. As is to be expected, the benefit-cost ratios of both projects declined as the discount rate increased from 10 percent to 15 percent.

The Internal Rate of Return

The internal rate of return is defined as that rate of discount that equates the present value of project outlays with project benefits. In other words, it is the discount rate that reduces the present discounted value of net benefits to zero. This criterion ranks projects in accordance with the magnitude of their positive internal rate of return. A project is considered eligible for construction if its internal rate of return is greater than its opportunity rate of return or some other pre-specified rate.

Internal rates of return were computed for both projects and the results are shown in Column 3 of Table 7.2. As expected, this criterion, like the preceding two criteria, ranks the Kesem Project above the Megech Project. It is

TABLE 7.2

BENEFIT-COST RATIOS AND INTERNAL RATES OF RETURN, MEGECH AND KESEM RIVER PROJECTS

Projects	Benefit-Cost Ratio at Different Discount Rates 10%	12%	15%	Internal Rate of Return (%)
Megech River Project				
Strategy I - Animal Powered Operation	1.1	0.9	0.8	11
Strategy II - Semi-Mechanized Operation	1.7	1.4	1.1	17
Strategy III - Fully Mechanized Operation	1.5	1.3	1.0	15
Kesem River Project				
Semi-Mechanized Operation	2.7	2.3	1.9	27

SOURCE: Computed by author.

further noted that under comparable technological alternatives, both projects show attractive rates of return -- 27 percent and 17 percent, respectively. These rates of return, of course, compare rather favorably with the 10 percent rate of interest currently charged by the Agro-Industrial Bank of Ethiopia on agricultural loans.

Sensitivity Analysis

The sensitivity of the results with respect to the discount rate was formerly evaluated when varying discount rates were used to determine the present value of net benefits and the benefit-cost ratios. Both projects show very little sensitivity to changes in the discount rate between 10 and 15 percent. The discount rate must rise to 27 percent for the Kesem Project to show a benefit-cost ratio of 1 or a net present value of zero. The corresponding discount rate for the Megech Project is 17 percent. Therefore, as long as the social rate of time preference or the opportunity rate of return on social capital is less than the respective rates shown above, both projects will be socially profitable.

The sensitivity of the results with respect to changes in either estimated costs or estimated benefits was analyzed under the following three assumptions:

1. Actual annual benefits assumed to be 35 percent less than projected, costs remaining the same.
2. Actual annual costs assumed to be 35 percent

higher than projected, benefits remaining the same.

3. Actual annual costs assumed to increase by 20 percent and benefits to decrease by 15 percent of projected levels.

The sensitivity of both projects to the above assumed changes was tested using a discount rate of 10 percent. The Kesem Project showed a benefit-cost ratio of 1.8 under assumption (1), but the ratio increased to 2.0 when assumption (2) was invoked. A ratio of 1.9 was achieved under assumption (3). In general, however, it takes a decrease of around 60 percent in estimated benefits or an increase of about 171 percent in estimated costs for the Kesem Project to show a B/C ratio of 1. In more practical terms, this means that either estimated yields or product prices, other factors remaining the same, must decline by over 60 percent for the Kesem Project not to be socially profitable.

The Megech River Project, however, is more sensitive than the Kesem Project with regard to unfavorable benefit and cost outcomes. It shows a benefit-cost ratio of slightly over 1 under assumption (1), but the ratio rises to 1.2 when assumption (2) is invoked. Under assumption (3), the Megech River Project shows a benefit-cost ratio of 1.1. Either estimated costs must increase by around 58 percent or estimated benefits must decrease by about 36 percent for the Megech Project to show a benefit-cost ratio of less than 1. Therefore, other things remaining constant,

the Megech Project will remain socially profitable as long as either estimated yields or product prices do not drop by more than 36 percent or input prices do not rise by more than 58 percent above the projected values.

So far the discussion has concentrated on the direct benefits of the prospective projects. But these projects do have secondary and spin-off benefits that should be considered. These will now be briefly examined.

Repercussion Effects

Although the two projects are likely to have the same pattern of repercussion effects on the economy, the magnitude of these affects will, of course, be different depending on the relative size and location of the projects. The scope of this study did not allow a comprehensive analysis of these effects, but it seems in order to comment generally upon their possible magnitude and direction.

To begin with, the repercussion effects flowing from these two projects may be felt either through or outside the market. While some kind of market values may be obtained directly or indirectly for many of these effects, others have to be evaluated on the basis of qualitative information. Under these circumstances, the analysis does tend to be influenced by value judgments, but despite this danger of bias, whatever little light one may shed on this issue would seem to be of value to the policy decision-maker.

Four major areas of repercussion effects were considered particularly worthy of discussion in this study. These include inter-industry impact or, more technically, household consumption and business multiplier effects, capital accumulation through reinvestment of earnings, effect on balance of payments, and a wide range of extra-market costs and benefits.

A. Inter-Industry Impact

Short of employing a formal input-output model, it is not possible to fully assess the inter-industry impact of these projects. Since there is no input-output table developed for Ethiopia, and it is beyond the scope of this study to develop one, a very crude approach is used here to arrive at some indication of the inter-industry impact of the projects.

Intuitively, it is clear that projects of the sort suggested in this study will have impacts on a wide range of industries. The magnitude of the impact, however, is likely to be more discernable only among certain kinds of industries. Obviously, the impact will likely be more direct and measurable on those industries that supply goods and services to the projects and those that process and market the projects' outputs. These industries will experience increased activity as a result of doing business with the projects; therefore, the additional income that these industries generate as a result of doing business with the

new projects constitutes a direct spin-off from the projects.

In conventional benefit-cost terminology, this kind of spin-off falls within the bounds of secondary benefits. As already pointed out elsewhere, secondary benefits may be classified into two categories: (1) secondary benefits induced by the project, and (2) secondary benefits stemming from the project. Induced benefits are the added values or net profits generated by firms and industries that supply production inputs and consumer goods to the project and project employees, respectively. Secondary benefits stemming from the project, on the other hand, are the added values generated by the firms and industries that process, transport, and market the projects' outputs.

Quantitative estimates of secondary benefits are, however, difficult to establish in the absence of complete and detailed data regarding inter-industry flows of goods and services. Despite such limitations, it seems desirable to provide some rough idea of the magnitude of secondary benefits that may be expected from the proposed projects. Accordingly, some crude indirect benefit factors were used to estimate the secondary benefits. Assuming the long term profits of both the supply and processing industries in Ethiopia to be in the neighbourhood of 5 percent, the Kesem Project will generate approximately E \$177,000 in induced benefits and about E \$311,000 in stemming from benefits, or a total secondary benefit of approximately E \$488,000.

The Megech Project, on the other hand, will show an estimated E $112,000 in induced benefits and E $292,000 in stemming from benefits, or a total secondary benefit of approximately E $404,000. Although one should not attach too much importance to the above figures, it is nevertheless intuitively clear that in an underdeveloped country like Ethiopia a new investment of the kind considered here will have significant secondary benefits.

B. Capital Accumulation

Another important repercussion effect of the investment projects considered in this study is their potential contribution to capital formation in Ethiopia. In a country where there is a dearth of agricultural capital, any project that can generate reinvestable funds can be of great assistance to agricultural and economic development.

The potential capacity of the two projects for generating reinvestable funds seems to be considerable. A close examination of the revenue patterns of the projects indicates that the Kesem Project can generate up to a maximum of approximately E $5.2 million annually after 11 years of operation, while the Megech Project can contribute up to a maximum of E $3.6 million annually after 14 years of operation.[1] These estimates, of course, assume that all the

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[1] The number of years specified refers to the time period required by the projects to show positive net present value of benefits when discounted at 10 percent.

annual net benefits generated by each project would be potentially available for investment. To realize this potential, however, it would be necessary to institute appropriate policy instruments specifically designed for mobilizing and channelling these funds into productive investment.

C. Effect on Balance of Payments

The implementation of either of the proposed projects will certainly require a considerable amount of imported inputs. According to present project plans, a considerable portion of the construction materials, all of the machinery and complements, fuel, and agricultural chemicals required for anticipated project operation must be imported from abroad. Since foreign exchange is a limiting factor in Ethiopia, it is essential to carefully appraise the foreign exchange requirements of both projects and suggest some means by which the needed foreign exchange may be raised.

The estimated average annual foreign exchange requirements of the two projects are shown in Table 7.3. Under the assumption of a semi-mechanized technology, the Megech Project will require about E $945,000 worth of imported capital yearly, while the Kesem Project's annual requirement would amount to approximately E $1.9 million.

The required level of foreign exchange can be allocated to the projects from the available annual foreign exchange earnings or part of the projects' output can be

TABLE 7.3

ESTIMATED ANNUAL FOREIGN EXCHANGE REQUIREMENTS OF MEGECH AND KESEM PROJECTS

Project	Amount of Foreign Exchange Required Per Annum	Percent of Annual Gross Output Required to Pay for Imports
	(In '000 of 1970 Eth. Dollars)	
<u>Megech Project</u>		
Strategy I	547.76	16.5
Strategy II	964.97	21.9
Strategy III	2,407.52	39.2
Improved Practices Without Project	304.63	12.0
<u>Kesem Project</u>		
Semi-Mechanized Operation	1,899.66	34.7

<u>Note</u>: Column (2) computed on the basis of the 1970 exchange rate - E $1.00 = U.S. $0.40.

Column (3) percentage based on output level after full development.

SOURCE: Computed by author.

exported to pay for the required imports. If the latter policy is adopted, the Megech Project will need to export approximately 22 percent of its annual output, while the Kesem Project will have to export as much as 35 percent of its gross annual output (Table 7.3). Although the projects do have the potential to pay for the needed foreign exchange expenditures and even raise additional foreign exchange, domestic food requirements would probably dictate that the projects output be directed towards the substitution of food imports. Annual expenditure on food imports averaged around E $24.8 million between 1969 and 1972[1] and the trend appeared to be upward.

It must, nevertheless, be pointed out that the foreign exchange requirements of these projects may be less than estimated if a serious effort is made to use locally produced materials as long as reasonable substitutes are available or can be made available on request. In some cases, a very careful survey of the local markets may reveal the availability of adequate domestic substitutes for certain imports, at other instances, it may be possible to induce domestic firms to produce and supply certain materials that they do not normally produce for lack of markets. On the whole, therefore, efforts to minimize the foreign exchange requirements of these projects must be an integral part of

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[1] Imperial Ethiopian Government, Central Statistical Office, Statistical Abstract, 1972, p. 89.

project operation.

D. Extramarket Costs and Benefits

Besides the tangible and measureable repercussion effects, both projects also involve intangible costs and benefits. The size of such costs and benefits cannot be measured in monetary terms, but their impact on the welfare of the society and the participants of the project in particular is as real as those for which market values exist. Therefore, it seems desirable to give consideration to extramarket costs and benefits. This section attempts to enumerate briefly the most important extramarket costs and benefits that may result from the proposed projects.

1. Extramarket Costs

These include the potential disutilities and disamenities that society at large incurs as a direct result of the creation of the proposed projects. Two types of extramarket costs appear to be of vital importance in connection with these projects: (1) the environmental hazards of the spread of diseases associated with irrigation in a warm climate (for example, malaria and schiztosomiasis), and (2) the disruption of the participants' traditional way of life.

The widespread availability of water in a hitherto dry area is likely to aid the spread of waterborne diseases. Diseases that thrive best in warm wet areas such as malaria

and schiztosomiasis represent a major health hazard in irrigated regions of the tropics. Unless a vigorous environmentmental health program is launched along with the implementation of the projects, disasterous health problems could arise primarily from these sources.

An equally important concern is the social cost associated with the disruption of the traditional way of life of the project participants. Some dislocation of community life would be unavoidable during the period of adjustment to the new way of life. However, in order to minimize such costs and ensure the success of the program, it seems essential to give the participating farmers sufficient opportunity to be involved in the planning and decision-making process from the very start of the program. A serious effort should also be made to make the transition as smooth as possible.

2. Extramarket Benefits

Extramarket benefits, of course, refer to certain recognizable and discernable utilities and amenities that the project participants and the wider community may enjoy as a result of the establishment of the projects. Such benefits are likely to be of a wide ranging nature. Perhaps first and foremost is the augmentation of the national food supply which either or both of these projects make possible. The insurance against drought that the projects provide in a country where significant portions of the geographic area

have a history of recurrent droughts and crop failures can be extremely important. Closely tied to this fact are the social benefits that could flow from reduced incidence of certain waterborne diseases and increased productivity as a result of provision of clean community water supplies both for household use and livestock consumption.

Extramarket benefits are also likely to accrue to project participants in terms of prospects for better and improved community life, building a strong foundation for future industrial growth and improved amenities in the areas of health, education and cultural activities.

Results of Financial Analysis

While economic analysis is concerned with the overall evaluation of benefits and costs and the relative position of the particular project in the economy as a whole, financial analysis has the more restricted purpose of determining whether the expected annual revenues from the project will be sufficient to cover the corresponding annual expenditures. The methods of project financing and cost repayment are also closely associated with financial analysis. Although it has been assumed that the proposed projects will be publicly financed, it should be pointed out that the method of financing adopted by the government could have different impacts on the economy.

<u>Comparison of Annual Revenue and Outlay</u>

The key question in financial analysis is whether sufficient revenue can be raised to cover the costs of the project. Intimately connected with this concept are the questions of whether or not the project cost is to be reimbursed and if so, how much of it is to be repayed, who should pay and how and when is the repayment to be collected.

A comparison of the annual revenues and annual outlays of the two projects proposed in this study indicates that the Kesem Project will require five years for annual revenues to exceed annual outlays, while the Megech Project would require six years. Annual outlays in this particular instance include both project and associated costs. Interestingly enough, revenues exceed operating costs (i.e., operation maintenance, replacement and production costs) right from the very first year of operation for both projects.

The repayment capacity of both projects was examined using discounted cash flow analysis. At a discount rate of 10 percent, the Kesem Project can pay-off all the accumulated investment costs in 11 years while the Megech Project would require a pay-off time of 14 years provided that the semi-mechanized strategy is adopted (Table 7.4).

Based on their capacity to generate revenue, both projects demonstrated that they have the capability to repay the capital investment and accrued interest at 10 percent in a reasonably short period of time. This analysis, of course, assumes that all of the net operating revenue

TABLE 7.4

RESULTS OF CASH FLOW ANALYSIS, MEGECH AND KESEM RIVER PROJECTS

Projects	Number of Years Required for Annual Revenue to Exceed Annual Outlay	Pay-Off Period at 10% Discount Rate
Megech River Project		
Strategy I - Animal Powered Operation	7	26
Strategy II - Semi-Mechanized Operation	6	14
Strategy III - Fully Mechanized Operation	6	15
Kesem River Project		
Semi-Mechanized Operation	5	11

SOURCE: Computed by author.

will be applied toward the repayment of the project costs. This assumption is valid since family living allowances have already been accounted for in the associated costs. If, however, this stringent requirement is relaxed so that repayment will be shared by indirect beneficiaries, full repayment can be made in an even shorter period of time.

Methods of Financing the Projects

These projects are expected to be financed from public revenue. But a detailed examination of the wide range of public financing techniques and their probable impacts on Ethiopia's economy as a whole are beyond the scope of this study. Nevertheless, it seems necessary to allude briefly to the most important methods available to the Ethiopian government to finance the proposed projects.

To begin with, it is important to make a distinction between the foreign exchange portion and the domestic portion of the financing problem. Although the initial foreign exchange expenditures required by the proposed projects are expected to come from either uncommitted earnings or funds diverted from other low priority imports, loans or assistance from foreign sources including government, private and multilateral agencies may provide alternative sources of foreign exchange. However, long run self-sufficiency in foreign exchange would require that the crop plan include exportables or import substitutes.

The purely domestic portion of the financing, of

course, must be raised from domestic sources. Normally governments have three major avenues of raising funds for financing public projects, namely, issuing bonds, borrowing from the national bank or credit creation, and general tax revenues. Under Ethiopian conditions, issuing bonds to finance the proposed projects does not seem to be a viable method primarily because the capital market is not yet well developed. The government is, therefore, left with only two choices. They can either borrow from the national bank and hence resort to deficit financing or make budgetary appropriations from general tax revenues to finance the project. Which of these two methods is preferable depends, among other things, on the state of the economy at the time the expenditure is made. Under conditions of general unemployment and depressed prices, deficit financing has a decided advantage. Since the projects are expected to be small relative to the economy and their impact on the general level of prices is expected to be limited, financing through credit creation is likely to have a favorable impact on the economy as a whole. On the contrary, if at the time of implementation of the projects the economy is experiencing inflationary situations the necessary funds must be appropriated to the projects from general tax revenues. Direct user charges or special taxes may be levied to recoup the investment costs. But the relative social and administrative merits of these and possibly other repayment methods must be carefully assessed before they are implemented.

Impact of the Two Projects on Foodgrain Production and Labor Employment

One of the objectives of this study was to evaluate the impact of public investment in agricultural water development in Ethiopia on foodgrain production and employment. The impacts of the projects on these parameters have been carefully analyzed and the results of the analysis are presented below.

First, it is important to point out that according to the results of the economic analysis discussed earlier in this chapter, both projects are economically viable. The Kesem Project shows a potential internal rate of return of 27 percent over 40 years, while the Megech Project has a potential internal yield of 17 percent over the same planning horizon. These rates of return are significantly higher than the assumed social opportunity rate of return of 10 percent per annum. Hence it can be safely concluded that investment in agricultural water development does have a significant potential for yielding social rates of return that are fairly competitive with returns from investments in other sectors of the Ethiopian economy.

Second, these projects also show a favorable impact on both foodgrain production and labor employment. An examination of Table 7.5 reveals that the Kesem River Project has the potential of increasing annual foodgrain production by a total amount of 24,577 tons. This quantity

TABLE 7.5

FOODGRAIN PRODUCTION POTENTIAL OF MEGECH AND KESEM RIVER PROJECTS

Projects	Annual Foodgrain Production (Tons)	Index of Food grain Production Traditional Practice = 100	Index of Food-grain Production Improved Practice Without Project = 100
Megech River Project			
Strategy I - Animal Powered Operation	17,081	295	150
Strategy II - Semi-Mechanized Operation	22,975	398	202
Strategy III - Fully Mechanized Operation	23,560	408	207
Output Without Megech Project			
Traditional Practices	5,772	100	51
Improved Practices	11,367	196	100
Kesem River Project			
Semi-Mechanized Operation	24,577	--	--

Note: Column (2) was computed according to the following formula:

$$Q_j^r = \sum_{i=1}^{N} Y_{ij}^r H_{ij}^r, \quad i=1,\ldots,N; \quad r=1,\ldots,V; \quad j=1,\ldots,M$$

where: Q_j^r = total foodgrain production potential of project j under strategy r in metric tons,

Y_{ij}^r = average yield level of i^{th} foodgrain in j^{th} project area under strategy r after full development in metric tons.

H_{ij}^r = number of hectares of land allocated to the i^{th} foodgrain in the j^{th} project area under strategy r after full development,

N = number of foodgrains in the optimal crop mix of project area j under strategy r,

M = number of projects considered,

V = number of strategies specified for each project.

represents a net addition to Ethiopia's food supply, as the Kesem Project area is not expected to produce foodgrains without the project. The Megech River Project, on the other hand, has the capability for producing up to 22,975 tons of foodgrains annually (under the semi-mechanized operation), which compares rather favorably with the estimated present annual output of 5,772 tons or the 11,367 tons expected to be produced annually under improved practices without the project. It is therefore evident that investment in agricultural water development in Ethiopia has a definite potential for significantly increasing foodgrain production.

As regards the employment generating capacity of these projects, the figures in Table 7.6 show that potential employment with the projects is appreciably larger than employment conditions without the projects. More specifically, the Kesem Project is expected to provide job opportunities for 4,499 in an area that does not support more than 500 workers in its present or foreseeable use without the project. In contrast, the Megech River Project area presently employs about 3,461 agricultural workers; but this number can increase to about 4,493 if improved practices without the project are adopted. With the project, under the semi-mechanized operation, the employment level would increase to 4,672 workers. The induced employment effect in the processing and marketing sectors have not been assessed because of lack of data, but some increase

TABLE 7.6

EMPLOYMENT GENERATION POTENTIAL OF MEGECH AND KESEM RIVER PROJECTS

Projects	Total Number of Workers	Number of Unskilled Workers	Number of Skilled Workers
Megech River Project			
Strategy I - Animal Powered Operation	4,692	4,458	234
Strategy II - Semi-Mechanized Operation	4,672	4,065	607
Strategy III - Fully Mechanized Operation	1,213	134	1,079
Employment Without Megech Project			
Traditional Practices	3,461	3,461	--
Improved Practices	4,493	4,358	135
Kesem River Project			
Semi-Mechanized Operation	4,499	3,914	585

Note: The total number of workers required by the projects is estimated according to the following formula:

$$E_k^r = \sum_{i=1}^{N} \sum_{j=1}^{M} L_{ijk}^r H_{jk}^r + P_k^r, \qquad i=1,\ldots,N; \quad j=1,\ldots,M; \quad k=1,\ldots,S; \quad r=1,\ldots,V$$

where: E_k^r = the total number of workers required by project k under strategy r after full development,

L_{ijk}^r = labor requirement of the ith farm operation, per hectare of crop j in the k^{th} project area under the r^{th} strategy (in number of workers per year),

H_{jk}^r = the number of hectares allocated to crop j in the k^{th} project area under the r^{th} strategy after full development,

P_k^r = the number of administrative, professional, clerical, technical and service personnel required by project k under the r^{th} strategy,

N = the number of farm operations per crop planted,

M = the number of crops in the optimal crop mix,

S = the number of projects considered,

V = the number of strategies specified for each project.

in employment can justifiably be expected in these sectors as more labor would be required to handle the anticipated increase in output. These results, therefore, clearly indicate that both projects display very interesting potentials for rural employment generation.

In the final analysis, while it is imprudent to conclude on the basis of this study alone that investment in water development is the answer to Ethiopia's food and unemployment problems, the facts as analyzed in this study suggest that investment in this area promises to be a very viable and attractive alternative. From the available evidence, it is clear that the twin economic problems confronting Ethiopia -- food and unemployment -- can be successfully tackled through a water oriented investment policy. Hence water development deserves closer attention from economic planners and policy-makers than it has received in the past.

Policy Implications of the Study

Although one should guard against broad and unwarranted generalizations, there is no doubt that some interesting policy implications emerge from the present study. Given the fact that increases in foodgrain production must come either from increasing yields per hectare or from expanding cultivated area, or both, substantial advance in either of these directions does not seem possible in

Ethiopia without sizable investment in water development. The present study provides evidence, admittedly limited, but nevertheless sufficient, to indicate that well planned and properly implemented agricultural water development schemes can markedly increase yields and enable expansion of cultivated area in both the highland and lowland regions of Ethiopia. The study, therefore, clearly suggests the direction agricultural development policy should take in Ethiopia.

The first implication of the present study is that agricultural and rural development policy in Ethiopia should take water development much more seriously than in the past. In this respect, not only should government investment policy emphasize irrigation and rural water supply development but incentives and various forms of inducement should be provided to private groups to conserve, develop, and efficiently manage the watersheds in which they live. The policy should further stress the conjuctive development and use of ground and surface water sources whenever such development is deemed feasible and rational.

The second policy implication involves the usefulness and applicability of the concept of multiple objective planning to the design and development of water resources in Ethiopia. The present study has illustrated that the twin objectives of increasing food production and generating employment are compatible enough to be successfully pursued through a single investment program. Likewise, it

has shown that community water supply development can be satisfactorily combined with irrigation schemes. Consequently, it is possible that future agricultural and rural development policies in Ethiopia can benefit significantly from the application of the concept of multiple objective planning. The application of this concept in water project appraisal can help reduce the duplication of effort and wastage of scarce resources that may accompany projects designed in pursuit of a single objective when the situation lends itself to multiple objective planning.

The third and final implication of the study is that with proper planning and investment, Ethiopia has the opportunity to use her water resource endowment as a leading source of economic growth. Ethiopia can generate economic activity on a broad front by putting water to work, along with other inputs, in the production of energy; production of food; including crop, livestock, and fisheries; preservation of wildlife; reforestation of barren lands; and the provision of a wide range of water services to households and industries. Although at present over 70 percent of Ethiopia's power supply comes from hydro-plants, the potential for the development of hydro-electric energy remains virtually untapped. Water development for other uses either by private interests or public agencies is rather negligible. Since economic development by definition involves the most efficient use of one's natural, human, and cultural resources, Ethiopia's economy is unlikely to show signifi-

cant growth as long as her natural and human resources remain unemployed on a vast scale.

In essence, then, the fundamental policy implication of this study is that investment in water development programs should be fostered and promoted in order to tackle both the short term food and unemployment problems and the long run economic development problems confronting Ethiopia. The successful development and efficient utilization of Ethiopia's water resources, however, require the existence of an appropriate institutional and organizational set up. To realize the potentially large social net benefits that Ethiopia can derive from agricultural water development, it is first necessary to establish institutional machinery that can effectively plan, organize, control and manage water resource development programs. Recognizing this fundamental requirement, an effort will be made in the subsequent chapter to briefly examine the existing institutional structure for water resource development in Ethiopia. Further, a proposal will be forwarded regarding an organizational form that will be suitable for the proper implementation of the projects suggested in this study.

CHAPTER VIII

INSTITUTIONAL ARRANGEMENTS FOR WATER RESOURCE DEVELOPMENT IN ETHIOPIA

Institutions are fundamental for any organized human endeavour. The existence of adequate and efficiently functioning water institutions is particularly important to the development and proper utilization of a nation's water resources. Institutions are required at various levels to cope with the many problems normally associated with water control and management. An essential function of water institutions is the resolution of conflicts among water users that normally arise as the use of the resource intensifies and supplies become scarcer.

In Ethiopia, the development of water institutions, particularly at the local level, has lagged behind the need for such institutions. Although a beginning has been made, much more remains to be done by way of developing the institutional framework that will foster the successful development and efficient utilization of Ethiopia's vast water resources.

In this chapter, the existing water institutions and the degree of their effectiveness in facilitating the control and management of Ethiopia's water resources will be reviewed. As well, an outline of the institutional needs

and arrangements for the proper implementation of the projects analyzed in this study will be presented.

Water Institutions in Ethiopia

Formal water institutions in Ethiopia have a relatively short history. The importance of water resources and the contribution that systematic water development can make to national economic development was not formally recognized until the early 1960's. The foundation for modern water institutions in Ethiopia was laid down during this period with the establishment of the Water Resources Department within the Ministry of Public Works and the creation of the Awash Valley Authority. The latter is an autonomous public agency responsible for administering the land and water resources of the Awash River Basin.

Although these two agencies have been pioneer national organizations in the water resources field, their activities to date have largely been restricted to the collection of hydrological and climatological data as well as the administration of routine departmental activities. Their performance record in the area of direct planning and development of water resources has been very poor. However, responsibility for the development and utilization of water resources has by no means been restricted to these agencies only. A number of ministerial departments, municipalities, and autonomous agencies such as the Ethiopian Electric

Light and Power Authority have also been involved in developing water resources for various uses including power, navigation, and municipal purposes.

Because of the overlapping nature of the responsibility for water resources development among various ministries and the wastage of resources entailed by such overlaps, the Ethiopian Government decided to establish a national Water Resources Council during the Third Five Year Plan (1968-73). The Council was to be an autonomous national water resource agency with powers to coordinate and control all activities relating to water resources in Ethiopia. In this connection the plan document states:

> In the development and planning of water resources, general river basin surveys, feasibility studies, climatological and hydrological data collection, etc., a large number of government ministries and agencies are presently responsible. In order to coordinate and integrate activities in this field, and advise the government on major policy issues of water resources development, a Water Resources Council will be established. The existing Water Resources Department in the Ministry of Public Works will be reorganized and will act as the technical secretariat of the Council.[1]

Among other things, the Council was given powers and responsibilities to collect data, make river basin surveys, prepare feasibility studies, design and construct rural water supplies, control water pollution, administer water rights, and supervise water legislation. Furthermore, the Council, through its technical agency, was assigned the

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[1] Imperial Ethiopian Government, Third Five Year Development Plan, 1968-73, p. 150.

responsibility of designing and constructing water development projects at the request of other government departments. The Council, therefore, has broad powers and duties as regards water resource development in Ethiopia.

Despite such official moves at the central government level, very little has been done by way of developing local institutions and enacting laws and regulations governing water rights. To date, no comprehensive water legislation has been considered in Ethiopia; hence, traditional and customary laws govern the use of both surface and ground water.

In Ethiopia, water has been traditionally considered a free resource, and the use of surface water for household purposes and livestock consumption is open to all users. The right of access to surface sources has also been traditionally guaranteed to all individuals and their livestock. The use of surface water for irrigation purposes, however, is commonly understood to be exclusive to the owners of riparian land. There seems to be no evidence to suggest that traditional practices ordinarily take into account the rights of downstream users.

Tradition and common law also govern the use of ground water. According to common practice, ground water rights are restricted to the owners of the overlying land surface. It is not clear what protection or recourse a ground water user has in the event of intrusions by neighbouring ground water users or interference by the users of

upstream acquifers. Likewise, the use of common ground water pools and common acquifers do not seem to be governed by any form of law, traditional or otherwise.

Most ground water uses in Ethiopia are restricted to domestic water supply and livestock consumption. Largely primitive methods are used to withdraw water from shallow wells and boreholes. Ground water use for irrigation purposes is almost nonexistent, apparently due to lack of proper technology to develop and utilize deep water wells.

In the past, lack of comprehensive water legislation and the absence of well defined property rights in water have not created serious difficulties. It seems that the absence of significant irrigation development and the generally low level of water utilization have kept the potential conflicts among water users to a minimum. But as demands for water increase with agricultural and industrial expansion, the traditional system of water allocation will undoubtedly prove to be very inadequate. Already it has come under severe strain in areas like the Middle Awash Valley, where irrigation agriculture has developed rather rapidly in recent years.

Amidst this traditional mileu, rather dramatic changes have occurred in Ethiopia's political structure over the last few years. Significantly enough, all the traditional social, economic and political institutions have been affected in one way or another by the recent change in government. Although the situation is still in a state of

flux, new laws have been decreed by the Provisional Military Government that fundamentally affect the nature of property rights in Ethiopia. According to the land reform law of March 1975,[1] all natural resources have been declared state property. Individuals or associations, however, can have use rights to both land and water provided that these resources are used for "prescribed purposes in a prescribed manner." This law, therefore, places under the direct control of the state the right to all water sources, surface and ground. It also firmly establishes that the development, control and management of water resources rests with the state or its appointed agents. The impact of these changes on water development, management and utilization is yet to be seen.

Government policy in the past has emphasized the development of water for hydroelectric purposes almost to the total exclusion of irrigation and other water uses. A continuation of this policy in the face of growing needs in other sectors will undoubtedly be irrational. Such a policy will also be very detrimental to agricultural and economic development in Ethiopia. There is therefore a definite need for a vigorous and comprehensive government policy to develop water resources on a broad front. An integral part of such a policy, of course, should be the

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[1] Provisional Military Administrative Council of Ethiopia, "A Proclamation to Provide for the Nationalization of Rural Lands, 1975 E.C."

encouragement and establishment of suitable local water institutions. Such institutions should be supported by a progressive water law governing the control, management and utilization of the nation's watersheds.

Institutional Requirement for Project Implementation

The implementation of the projects suggested in this study calls for a specific organizational structure. In the absence of local experience with water institutions in Ethiopia, it certainly is not easy to prescribe an institutional structure that can best suit the purpose at hand. Nevertheless, certain considerations seem to be vital when making institutional choices suitable for local watershed development in Ethiopia.

The first and perhaps most important consideration is the degree of grassroots or popular participation in the institutional machinery. If the institution is to be viable and effective, the full and complete involvement of the participating farmers in the institutional process must be ensured. Without effective popular participation in the decision-making process, the successful achievement of the projects' objectives can be in jeopardy. Second, the institutional structure must not be complex and cumbersome. On the contrary, it should be streamlined, simple, direct, and efficient. Overall, it must be an institution which

the participant can comprehend and call his own. This is essential because unless the participating farmers feel they are part of the institution, it will be difficult to maintain their enthusiasm and interest in the success of the institution.

One form of organizational structure that can meet the above requirements is a cooperative association of the participating farmers. Experience elsewhere in the world seems to indicate that cooperative associations are flexible institutions that can be adapted to a wide range of local situations. Although experience with farmers' cooperatives is still limited in Ethiopia, they are recommended in the present context because they show a potential to be viable and can be instrumental in bringing about an integrated approach between agricultural development and water management. Significantly, the use of farmers' cooperatives as institutional vehicles for social and economic change is being propounded by the present Ethiopian government.

The biggest drawback to the successful operation of modern cooperatives in Ethiopia is the lack of experienced membership that fully comprehends how cooperative organizations function. Undoubtedly, the success of the cooperative as an effective local institution depends on the ability of the members to work together toward a common goal. Although this condition may not be satisfied initially, an effective educational campaign should alleviate this problem in a relatively short period of time. Despite this

drawback, which incidentally may apply equally to other similar local water institutions such as public water districts and local water users associations, cooperative associations do have considerable merit as a democratic grassroots organization.

It should be emphasized, however, that as in other human endeavours, efficient management is crucial for the success of the organization. For this reason, a well qualified manager with sufficient experience and proven ability should be responsible for managing the cooperative. It is important to stress that the manager should not only possess technical skills in directing and controlling large-scale irrigation agriculture, but he should also be able to motivate and stimulate the participating farmers and project employees to a high degree of achievement.

It is further suggested that the manager should have a team of experts in the various technical specialities. These experts would be in charge of the various technical divisions and would assist the manager in their area of competence. The following specialities should be represented in the operation of the proposed cooperative association.

1. Agricultural Economist.
2. Agronomist.
3. Building Technolgist.
4. Education Specialist.
5. Farm Power Specialist.

6. Health and Sanitation Specialist.

7. Home Economist.

8. Irrigation Engineer.

Figure 8.1 shows a suggested organizational chart and line of responsibility.

In conclusion, the systematic development and efficient utilization of Ethiopia's water resources requires the existence of appropriate water institutions. Unfortunately, development of water institutions in Ethiopia, particularly at the local level, has lagged far behind the need. In recent years steps have been taken to establish a national water agency. However, lack of a comprehensive water law and the absence of a network of local water organizations that can give life and substance to national water policies continue to retard the rational exploitation of the nation's water resources.

In the past, Ethiopia heavily relied on tradition and custom to allocate water among various uses and to resolve conflicts among users. This system obviously is inadequate and ill-equipped to serve the complex development needs of Ethiopia. It will undoubtedly be seriously strained as the demand for water expands and competition among various uses becomes increasingly keen. Needless to say, the potential contribution water can make to agricultural growth and improvement of social welfare in Ethiopia critically depends on the existence of effective national and local water institutions.

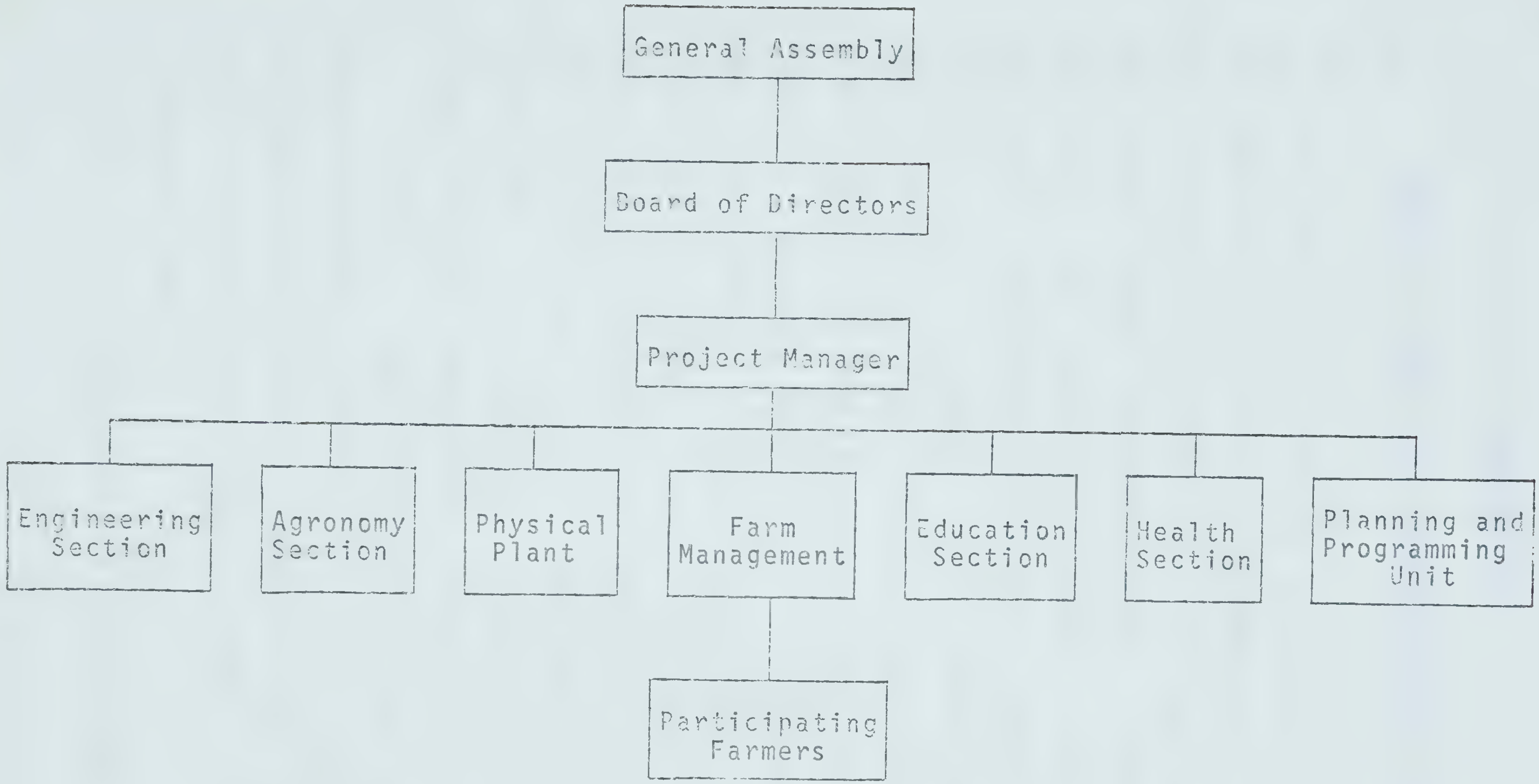

FIGURE 8.1

PROPOSED ORGANIZATIONAL CHART, MEGECH AND KESEM RIVER PROJECTS

CHAPTER IX

SUMMARY, CONCLUSION, AND RECOMMENDATIONS

The provision of adequate food supplies and productive employment for the expanding population represent the most pressing and challenging economic problems confronting Ethiopia today. The food problem in Ethiopia has been longstanding and is certain to linger into the future unless drastic measures are taken to substantially increase food production. An analysis of the demand and supply of food in the present study indicates that over the next decade, demand for food in Ethiopia will increase at an annual rate of about 4.2 percent, while food production over the same period is expected to grow at the meager annual rate of around 2.0 percent. Given the discrepancy between these two growth rates, Ethiopia's annual foodgrain shortfall over the next decade will be in excess of 157,000 tons. The unemployment problem is no less severe. Although official unemployment figures are unavailable, it is a matter of common knowledge that both unemployment and underemployment abound in Ethiopia. Recognizing the magnitude and implication of these problems, the present study has advanced and carefully analyzed a proposition for tackling them.

After discussing the nature and magnitude of

Ethiopia's food and unemployment problems, tracing their far-reaching consequences and analyzing their implication for Ethiopia's future economic and social development, public investment in agricultural water development was proposed as a vehicle for expanding food production and generating employment. The viability of this proposal was investigated both theoretically and empirically. Neo-classical theory of production and public investment theory provided the theoretical underpinning of the study. The empirical techniques of recursive programming and benefit-cost analysis were employed in conducting the detailed empirical analysis.

In the study, the resource base of Ethiopian agriculture, particularly agro-climatic diversity, was reviewed in some detail. The water resource potential of the country was also carefully examined. While the potential for irrigation development and the expansion of other uses of water appears to be considerable, the available information indicates that this potential, for the most part, remains untapped. Of the presently known 640,000 hectares of irrigable land, only about 60,000 hectares have been developed. In order to analyze the economic feasibility and evaluate the potential impact on food production and rural employment of developing these resources, two study areas, each representing one of the major agro-climatic regions of the country, were selected.

The Megech River area, in the Abay River Basin, was

selected to represent the highland regions of Ethiopia. This study area covers about 5,890 hectares of irrigable land and the proposed development was planned to be phased in over a ten year period, with approximately 10 percent of the land being developed each year. The initial capital requirement of the project was estimated at E $2.1 million (1970 dollars), with E $1.4 million being required annually over the ten year period for expansion of the irrigation infrastructure.

Under its most desirable alternative, the Megech Project yields an internal rate of return of 17 percent over a 40 year planning horizon. Annual revenues will equal total annual outlays (i.e., annual project cost + associated cost) during the sixth year after which the annual project revenues will exceed total annual costs. Cash flow discounted at 10 percent shows that the project has a pay-off period of 14 years. However, operating revenue exceeds operating cost right from the very first year. The project would require up to E $965,000 worth of imported goods annually. If foreign exchange earnings cannot be diverted to the project from other sectors, up to 22 percent of the gross output of the project will have to be exported to raise the required foreign exchange.

After full development, the Megech Project can produce an estimated 22,975 tons of foodgrain annually, which is roughly a two-fold increase over the expected level of production under improved practices without the project.

The direct employment effect of the Megech Project is estimated at 4,672 workers as compared to 4,493 under improved practices without the project.

The second study area selected was the Kesem River area located in the semi-arid plains of the Middle Awash Valley. The project area covers 5,650 hectares of irrigable land and, like the Megech project, the development program is expected to be phased in over a ten year period. Approximately 10 percent of the land is planned to be developed annually. The initial capital requirement for this project is estimated at E $2.4 million. About E $1.0 million in capital outlay would be required annually during the ten year expansion period. Approximately E $1.8 million worth of imported goods would be required annually to operate the project. To pay for this level of imports, up to 35 percent of the gross output of the project may have to be exported unless foreign exchange earnings can be diverted to the project from other accounts.

Analysis of the rate of return shows that the Kesem Project has an internal rate of return of 27 percent over a 40 year period and total annual outlays would equal total project revenue in five years. The pay-off period for the project, at a discount rate of 10 percent, would be 11 years.

The Kesem Project also demonstrates considerable potential for increasing foodgrain production. The successful implementation of this project can add up to 24,577

tons of foodgrain to the nation's food supply annually. It also has the potential to generate direct employment for approximately 4,499 persons. In addition, both projects have a wide range of positive net indirect or secondary effects which manifest themselves through inter-industry linkages, reinvestment of profits and general improvement of social welfare on a broad front.

In conclusion, therefore, it should be stated that both projects are economically attractive and they both demonstrate considerable potential for making significant contributions toward the solution of the food and employment problems in Ethiopia. In particular, the study has brought to the forefront the potentially important role public investment policy can play in stimulating agricultural development in Ethiopia. While the need for further, more intensive, studies in the economics of water development in Ethiopia should be stressed, this study has clearly pointed out the opportunities available to Ethiopia to significantly expand foodgrain production and stimulate rural development through the careful planning and efficient implementation of agricultural water supply development schemes. The social cost of continued neglect of such opportunities is incalculable.

Recommendations

In view of the results of the study and the policy

implications discussed in Chapter VII, the following recommendations appear worthy of serious consideration by the Ethiopian government.

1. The Ethiopian government should take appropriate measures to ensure that agricultural water development constitutes an integral part of Ethiopia's agricultural development strategy. The national development plans should reflect this commitment and adequate investment funds should be made available to implement the policy.

2. The Ethiopian government should give serious consideration to the establishment of a Department of Irrigation and Rural Water Supply within the Ministry of Agriculture. This department should have the means, powers, and responsibilities to promote, coordinate, and control water development for agricultural purposes, including irrigation, rural household and livestock water supply. Among the specific responsibilities of this department should be the direct undertaking of integrated water development programs as well as the provision of advice and technical assistance to rural households and local self-help groups. The absence of such a department within the Ministry of Agriculture has been an institutional deficiency and may have accounted, at least in part, for Ethiopia's failure to recognize and avail herself of opportunities for irrigation development provided by her water resource endowment.

3. In order to test the practicality and workabi-

lity of the public water development programs suggested in this study, it is recommended that pilot projects be established in each of the project areas studied. The pilot projects should be so designed as to allow full development if found workable.

Limitations of the Study

Aside from the limitations inherent in the assumptions on which the analytical techniques are based, two major limitations characterize this study. The first limitation is the quality and reliability of the data used in the study. Although every effort has been made to verify the validity and consistency of the data by comparing and re-checking with different independent sources, the quality of the data still leaves a lot to be desired. In several instances, unexplainable anomalies have been encountered among similar data obtained from different sources. However, in view of the general paucity of data in Ethiopia, this limitation was neither unexpected nor is it considered particularly unique to this study.

The second limitation arises from the possibility that the two study areas selected for this inquiry may not represent, as closely as assumed here, the broad range of physical and climatic conditions of Ethiopia. Obviously, for a country as large as Ethiopia, with its varied eco-system, a much larger number of areas representing the

different micro-climates and water resource systems must be studied before universally valid generalizations can be made regarding the social net benefits that would accrue from a nation-wide program of water development.

What these limitations mean, of course, is that the results of this study should be interpreted very carefully and cautiously. These limitations notwithstanding, the study has clearly indicated the direction which future agricultural development research and public investment policy should take in Ethiopia.

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APPENDIX A

Physical and Economic Setting of the Study

The origin of the problem considered in this study lies in the natural resource endowment of Ethiopia and the economic superstructure which has resulted from this endowment. An understanding of the physical and economic setting of the problem is, therefore, essential in order to put the problem in its proper perspective. The purpose of this appendix is to provide a brief discussion of the physical and economic basis of the problem so that its nature and magnitude can be properly understood.

Physical Setting

Ethiopia is a land of great physical diversity. Within its borders, Ethiopia includes areas that range from sea level coastal plains to alpine peaks reaching approximately 4,500 meters above sea level (Figure A.1). The direct result of this great variation in altitude is a very wide diversity in climate. Consequently, one finds a widely divergent microclimate within relatively short distances. These variations in climate in turn greatly influence both human settlement and agricultural practices (Figure A.2). Notwithstanding these broad variations in elevation, climate and agricultural practices, Ethiopia may be conveniently divided into two major agro-climatic regions -- the highlands which include areas lying above 1,800 meters and the lowlands which include areas lying below this elevation.

SOURCE: Mesfin Wolde Mariam, An Atlas of Ethiopia (Asmara, Ethiopia: II Poligrafico, Priv. Ltd. Co., 1970), p. 12.

FIGURE A.1

PHYSIOGRAPHIC REGIONS OF ETHIOPIA

SOURCE: Mesfin Wolde Mariam, An Atlas of Ethiopia (Asmara, Ethiopia: Poligrafico Priv. Ltd., 1970), p. 33.

FIGURE A.2

REGIONAL DISTRIBUTION OF FOOD PRODUCTION IN ETHIOPIA

The Ethiopian highlands stand out as the most prominent agro-climatic region in the country. Divided into the eastern and western plateaus by the great East African Rift Valley, the Ethiopian highlands are the home of the majority of the Ethiopian people and the source of the bulk of the nation's agricultural output. In general, the highlands have moderate daily temperatures throughout the year, averaging about 18°C, and receive an average annual rainfall of about 1,400 mm.[1] About 75 percent of the rainfall, however, occurs in a four month (June-September) period. The highlands experience rather pronounced dry and wet seasons, with the dry season lasting roughly six to eight months.

Relatively fertile and productive soils prevail over the highlands, although erosion is a very serious problem. Mixed agriculture prevails throughout the highlands, with livestock supplementing crop production. Dryland farming characterizes the agricultural production system. While temperature conditions in the highlands are generally suitable for the cultivation of crops throughout the year, lack of precipitation limits crop production to only one major harvest a year. The provision of supplemental irrigation,

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[1] For a detailed discussion on Ethiopia's climate, topography, and physical relief see Mesfin Wolde Mariam, An Atlas of Ethiopia (Asmara, Ethiopia: Il Poligrafico, Priv. Ltd., 1970); Assefa Bequele and Estatu Chole, A Profile of the Ethiopian Economy (Nairobi: Oxford University Press, 1969); F.J. Simoons, Northwest Ethiopia: Peoples and Economy (Madison: Wisconsin University Press, 1960); and Ernest W. Luther, Ethiopia Today (Stanford: Stanford University Press, 1958).

therefore, could make two harvests per year possible in many parts of the highlands.

The lowlands constitute the second major agro-climatic region of Ethiopia. They are basically vast semi-arid scrub lands that form the outside periphery of Ethiopia's land mass. They are generally characterized by high daily temperatures, the annual average temperature being in the range of 28°C - 30°C. As a rule, they experience very low rainfall, generally less than 400 mm per year, and the rainfall is usually unreliable. The moisture deficiency of these areas is further exacerbated by rather high rates of evapotranspiration stemming from the intense solar radiation.

In direct contrast to the highlands, the lowlands of Ethiopia are sparsely populated. Since they are largely inhabited by nomadic pastoralists, livestock raising constitutes the main form of economic activity. Although relatively good alluvial soils prevail in many parts of the lowlands, crop production is highly risky owing to moisture deficiency. Accordingly, if this vast area, estimated by some to be about 60 percent of Ethiopia's land area,[1] is to be utilized for crop production, water development will be absolutely essential.

Ethiopia's overall physical environment can generally be said to be characterized by widespread water scarcity. In many regions, not only is water development essential

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[1] Mesfin Wolde Mariam, An Atlas of Ethiopia, p. 12.

for expansion of crop production, it is also vital for the improvement of livestock performance. Likewise, the betterment of living conditions in general critically depend on the adequacy of developed water supplies. In the final analysis, then, the kind of response Ethiopia makes to the challenges posed by the scarcity of water seems to be one of the key factors determining the success or failure of her struggle for economic and social development.

Economic Setting

A characteristic feature of the Ethiopian economy is its heavy dependence on traditional agriculture. Although recent years have witnessed the emergence of the modern sector, peasant agricultural production still forms by far the largest sector of economic activity in the country.

Ethiopia's Gross Domestic Product (GDP) at constant factor cost of 1961[1] rose from E $2,323.3 million[2] in 1961 to E $3,450.6 million in 1970, thus registering an average annual growth rate of 4.0 percent over the ten year period

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[1] According to the Ethiopian Central Statistical Office, Gross Domestic Product at factor cost is less than Gross Domestic Product at market prices by the amount equal to the difference between indirect taxes and subsidies. Imperial Ethiopian Government, Central Statistical Office, Ethiopian Statistical Abstract (Addis Ababa: C.S.O., 1972), p. 117.

[2] E $1 = U.S. $0.40 in 1970 exchange rate. It should be noted that the U.S. dollar has since been devalued and the exchange rate in 1976 was E $1.00 = U.S. $0.50.

(Table A.1). Agricultural GDP increased at an average annual rate of 2.0 percent, from E $1,504.5 million to E $1,833.3 million over the same period. Although the major share of the GDP still originates from agriculture, the annual share of agriculture in the GDP steadily declined from 64.8 percent in 1961 to 53.1 percent in 1970, suggesting the emergence of a structural shift in the economy. Despite the decline in the share of agriculture in the GDP, employment in agriculture remained relatively unchanged at around 88 percent of the active labor force (Table A.2). During the same period, per capita income showed an average annual growth rate of only 2.1 percent, up from E $110.6 in 1961 to E $136.2 in 1970. This modest rate of growth in per capita income is largely a result of low productivity in agriculture.

In sharp contrast to the agricultural sector, the non-agricultural sectors showed a steadily increasing trend, with practically all of them registering average annual growth rates that were significantly higher than the rate of agricultural growth during the 1960's (Table A.1). The industrial sector, consisting of mining and quarrying, manufacturing, handicrafts, construction, and electricity, registered an average annual growth rate of 6.6 percent and increased its share in the GDP from 12.3 percent in 1961 to 15.8 percent in 1970. The wholesale and retail trade sector had an annual average growth rate of 7.8 percent and increased its relative share in the GDP from 6.0

TABLE A.1

GROSS DOMESTIC PRODUCT OF ETHIOPIA BY INDUSTRIAL ORIGIN (1961, 1965 AND 1970)
AT CONSTANT FACTOR COST OF 1961

Sector	1961		1965		1970		Average Annual Growth Rate Over Ten Year Period (1961-1970) (Percent)
	E $ Mil.	Percent of Total	E $ Mil.	Percent of Total	E $ Mil.	Percent of Total	
AGRICULTURE	1,504.5	64.8	1,670.3	59.2	1,833.3	53.1	2.0
Crop and Livestock	1,434.4	61.8	1,588.0	56.3	1,732.3	50.2	1.9
Forestry	65.9	2.8	77.7	2.8	96.5	2.8	3.9
Hunting	1.3	0.1	1.3	--	1.3	--	--
Fishing	2.9	0.1	3.3	0.1	3.2	0.1	1.0
INDUSTRIES	286.6	12.3	401.0	14.3	544.4	15.8	6.6
Mining and Quarrying	3.3	0.2	7.6	0.3	6.5	0.2	7.0
Manufacturing	43.9	1.9	79.6	2.8	142.9	4.1	12.5
Handicraft and Small Scale Industries	98.4	4.2	126.8	4.5	146.3	4.2	4.0
Building and Construction	130.8	5.6	165.8	5.9	209.2	6.1	4.8
Electricity and Water	10.2	0.4	21.2	0.8	39.5	1.1	14.5
WHOLESALE AND RETAIL TRADE	139.7	6.0	212.6	7.5	296.6	8.5	7.8
TRANSPORT AND COMMUNICATION	70.7	3.0	110.2	3.9	187.6	5.4	10.2

TABLE A.1 (CONTINUED)

Sector	1961		1965		1970		Average Annual Growth Rate Over Ten Year Period (1961-1970) (Percent)
	E $ Mil.	Percent of Total	E $ Mil.	Percent of Total	E $ Mil.	Percent of Total	
OTHER SERVICES	321.8	13.9	428.0	15.1	588.7	17.1	6.2
Banking, Insurance and Real Estate	20.2	0.9	27.4	1.0	39.5	1.1	7.7
Public Administration and Defence	88.9	3.8	141.0	5.0	182.2	5.3	7.4
Ownership of Dwellings	99.9	4.3	113.9	4.0	148.3	4.3	4.0
Educational Services	20.5	0.9	31.8	1.1	61.0	1.8	11.5
Medical and Health Services	13.8	0.6	20.8	0.7	24.2	0.7	5.8
Domestic Services	51.2	2.2	54.2	1.9	59.6	1.7	1.6
Miscellaneous Services	27.3	1.2	38.9	1.4	73.9	2.1	10.5
TOTAL	2,323.3	100.0	2,822.1	100.0	3,450.6	100.0	4.0
POPULATION ('000)	20,989.1		22,698.6		25,338.3		1.9
PER CAPITA INCOME (In 1961 Eth. $)	110.6		124.3		136.2		2.1

SOURCE: Imperial Ethiopian Government, Central Statistical Office, Ethiopia: Statistical Abstract (Addis Ababa: Central Statistical Office, Various Issues, 1963-1972).

TABLE A.2

ESTIMATED EMPLOYMENT OF ACTIVE LABOR FORCE, ETHIOPIA (1966, 1968 AND 1970)

Sector	1966		1968		1970	
		Percent of Total		Percent of Total		Percent of Total
Agriculture	10,526,137	89.09	10,858,000	88.88	10,975,227	88.17
Manufacturing Industry	42,343	0.36	48,652	0.40	51,313	0.41
Food	9,790	--	8,583	--	8,589	--
Beverages	2,473	--	3,155	--	2,910	--
Tobacco	1,095	--	562	--	542	--
Textile	17,040	--	21,656	--	22,342	--
Leather	2,298	--	2,001	--	2,177	--
Wood	2,147	--	3,111	--	4,018	--
Non-Metallic	3,684	--	3,822	--	3,866	--
Printing	1,403	--	1,579	--	1,548	--
Chemical	1,613	--	2,563	--	3,126	--
Metal and Electrical	903	--	1,620	--	2,194	--
Services (Including Public Sector)	1,247,160	10.55	1,310,407	10.72	1,421,070	11.42
Total	11,815,640	100.00	12,217,060	100.00	12,447,610	100.00

SOURCE: Imperial Ethiopian Government, Central Statistical Office, Ethiopia: Statistical Abstract (Addis Ababa: Central Statistical Office, Various Issues, 1967-1972).

percent in 1961 to 8.6 percent in 1970. This was repeated by the transport and communication sector, which showed an average annual growth rate of 10.2 percent and increased its contribution to the GDP from 3.0 percent to 5.4 percent at the end of the decade. The service industries, such as banking, insurance and real estate, public administration, health, education, etc., had a growth rate of 6.2 percent and also increased their relative share in the GDP from 13.9 percent in 1961 to 17.1 percent in 1970.

Although these growth rates are impressive, it should be mentioned that these sectors started from a very low initial base; hence, even a small absolute change would result in a relatively large percentage change. But the figures forcefully bring out two fundamental points that have far reaching implications for future investment planning in Ethiopia.

First, despite their rapid growth rates, the non-agricultural sectors have not generated sufficient employment opportunities to perceptibly reduce the size of the agricultural labor force. Hence, presently the country finds itself in a situation where an estimated 88 percent of the active labor force is still engaged in low productivity agriculture which produces only about 53 percent of the Gross Domestic Product. Both the output/labor ratio and the capital/labor ratio in agriculture are much lower than the corresponding values for the non-agricultural sectors. This anomally, of course, is a direct result of

government investment policy which neglected agriculture in favour of the non-agricultural sectors. Agricultural investment in Ethiopia between 1961 and 1965 was estimated at about 0.5 percent[1] of the GDP, and only 11.58 percent of the total gross planned investment in the Third Five Year Plan (1968-1973) was allocated for agriculture and allied activities.[2] Furthermore, compared to other developing countries in Africa, Latin America, and Asia, Ethiopia ranks among the lowest in terms of total agricultural expenditure as a percent of total budgeted expenditures.[3] The effect of this policy has been to keep labor and land productivity in agriculture very low, while producing only marginal results in terms of employment generation outside agriculture.

Secondly, the rapid rates of growth in the industrial and service sectors have not led to high growth rates in per capita income. This result seems to reinforce the widely held view that in a developing country like Ethiopia,

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[1] E.F. Szezepanik, "The Size and Efficiency of Agricultural Investment in Selected Countries," Monthly Bulletin of Agricultural Economics and Statistics, Vol. 18 (December, 1969), p. 2.

[2] Imperial Ethiopian Government, Third Five Year Development Plan, 1968-1973 (Addis Ababa: Berhanena Selam Press, 1968), p. 59.

[3] J.H. Robinson and Mammo Bahta, An Agricultural Credit Program for Ethiopia, Report No. 9 (Menlo Park, California: Stanford Research Institute, January, 1969), p. 41.

significant improvement in per capita income cannot be realized, even in the face of rapid growth in the non-agricultural sectors, until the productivity of the agricultural labor force is significantly increased and the rate of population growth is slowed down.

Within the Ethiopian agricultural sector, crop and livestock production account for the largest share of the output while forestry, hunting and fishing as a group play only a minor role. In 1970, about 94.5 percent of the agricultural production consisted of crop and livestock output. The rest was made up of forestry (5.2 percent), hunting (0.1 percent), and fishing (0.2 percent) (Table A.1). Hunting has increasingly become a very negligible activity, while forestry and fishing have shown only slight improvements over the past decade. The value of crop and livestock output, on the other hand, increased at an annual average rate of 1.9 percent, up from E $1,434.4 million in 1961 to E $1,732.3 million in 1970. Nevertheless, the relative share of crop and livestock output in the GDP declined from 61.8 percent in 1961 to 50.2 percent in 1970 (Table A.1).

Presently, the crop and livestock sectors are the major sources of livelihood for a significant proportion of the population. It is estimated that close to 90 percent of the population still lives in the rural areas and is believed to be directly or indirectly dependent on the land.

Judging by the past performance of the Ethiopian economy, the employment structure is unlikely to change

significantly in the foreseeable future. The agricultural sector, therefore, must continue to provide employment and the means of livelihood for increasing numbers of people in the 1980's and 1990's. This, however, is not to say that the labor force is fully employed now. Although official unemployment figures are unavailable, it is widely believed that significant unemployment and underemployment exist in the rural areas. It has been suggested that the rate of urban unemployment may be as high as 15-20 percent.[1] The unemployment problem can be expected to worsen as the population continues to surge upwards at the estimated rate of 2.5 percent[2] in the 1970's and 1980's. The fact that the population is disproportionately distributed between urban and rural areas means that most of the population pressure will be felt in the rural areas, although the towns will not be spared the onslaught as scarcity of opportunities in rural areas forces mass migration to the cities. The urban population is currently expanding at an annual rate of about 6.6 percent, of which 4 percent is believed to be due

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[1] Edwin Cohn and John Eriksson, "Employment and Income Distribution," War on Hunger, A Report of the Agency for International Development (Washington, D.C.: USAID, July, 1973), p. 12. For a broader discussion of the unemployment problem in Ethiopia, see Yilma Teklemariam, "Issues in Labor Unemployment and Migration in Ethiopia" (University of Alberta, Department of Agricultural Economics, Edmonton, 1973). (Typewritten.)

[2] Imperial Ethiopian Government, Central Statistical Office, Ethiopia: Statistical Abstract (Addis Ababa: CSO, 1972), p. 20.

to net immigration from rural areas.[1] Given these salient facts, it is quite clear that in the foreseeable future only rapid expansion in rural development can provide relief to the massive unemployment problem in Ethiopia.

The contribution of the agricultural sector to the Ethiopian economy, however, is far more pervasive than simply the provision of a means of livelihood for the great majority of the population. Farm commodities account for over 95 percent of Ethiopia's exports, with coffee alone accounting for about 60 percent of the foreign exchange earnings (Table A.3). The implication of this state of affairs in terms of Ethiopia's need for increasing amounts of foreign exchange to pay for much needed capital and fuel imports is indeed far reaching. Consequently, the need to diversify and expand exports is very urgent for Ethiopia.

The agricultural sector also plays a vital role in providing the raw material base for most of Ethiopia's manufacturing industry. As is to be expected, firms dependent on a wide range of agricultural raw materials constitute a major proportion of the manufacturing industry in Ethiopia. In 1970, for instance, about 75.9 percent of the gross value of production in the manufacturing sector originated in agriculturally based industries.[2] During the same year,

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[1] Ibid.

[2] Imperial Ethiopian Government, Central Statistical Office, Ethiopia: Statistical Abstract, 1972, pp. 56-57.

TABLE A.3

ETHIOPIA'S EXPORT TRADE (1961, 1965 AND 1970)

Commodity	1961		1965		1970		Average Annual Growth Rate Over Ten Year Period (Percent)
	E $ ('000)	Percent of Total	E $ ('000)	Percent of Total	E $ ('000)	Percent of Total	
Coffee	93,874	50	188,347	65	181,268	61	6.8
Oilseeds and Cakes	17,374	9	28,331	10	28,353	10	5.0
Cereals and Pulses	18,027	10	15,117	5	15,800	5	2.0
Skins and Hides	25,134	13	23,523	8	24,465	8	1.5
Meat, Canned and Frozen	3,213	2	7,405	3	5,969	2	6.4
Animals and Chickens (Live)	456	--	3,139	1	2,317	1	14.9
Fruits and Vegetables	4,070	2	5,392	2	3,232	1	1.6
Other	21,350	11	11,786	4	22,933	8	.7
Re-Exports*	5,125	3	6,788	2	11,267	4	8.2
Total	188,623	100	289,833	100	295,604	100	4.6

* Re-Exports are imported goods subsequently re-exported without change of form.

SOURCE: Imperial Ethiopian Government, Central Statistical Office, Ethiopia: Statistical Abstract (Addis Ababa: Central Statistical Office, Various Issues, 1963-1972).

these industries employed 79.2 percent of the industrial labor force.[1] The future expansion of these industries and the establishment of similar new industries will undoubtedly require expanded and increased farm output to provide the necessary raw materials.

The wholesale and retail trade sector is also dependent on the performance of the agricultural sector. In as much as a large proportion of the goods that flow through the trade sector are farm commodities, the future expansion of this sector is also closely tied to the growth of agricultural output. The development of low cost transportation and an efficient marketing system can contribute to the growth of the wholesale and retail trade. But without substantial increases in agricultural output, and consequently, marketable surplus, the wholesale and retail trade sector in Ethiopia cannot provide the potentially high level of employment and income that it is capable of providing.

The single most important contribution of Ethiopian agriculture to national welfare, however, is the provision of domestic food supply. The provision of foodstuffs for home consumption forms the primary basis of agricultural production in Ethiopia. For the most part, it is family consumption needs rather than profit maximization that motivates the large majority of individual farm operators in Ethiopia. Therefore, in most cases, only surplus quanti-

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[1] Ibid.

ties over and above individual family needs are traded in order to acquire other items not produced on the family farm. The marketable portion of the output is a relatively small percentage of the total output -- perhaps not exceeding 20 percent.

The domestic production of adequate food supplies, of course, is of crucial importance to Ethiopia. Since scarcity of foreign exchange severely limits Ethiopia's capacity to augment her domestic food supply through substantial imports from abroad, practically all of the national food consumption requirements must be produced at home. Ethiopian agriculture, therefore, has the burdensome task of adequately feeding a rapidly expanding population. Unfortunately, as events in recent years have shown, this task has proven to be exceedingly difficult.

As has been pointed out, the performance of Ethiopian agriculture in the 1960's was disappointing. Although agricultural output as a whole increased at an average annual rate of 2.0 percent between 1961 and 1970, the crop and livestock sector, which constitutes almost the entire source of food supply, had an average annual growth rate of 1.9 percent, a rate identical with that of population growth for the same period. Therefore, food production barely kept up with population growth.

Per capita food output increased slightly between 1964 and 1971 (Table A.4). Per capita production of calories and proteins increased by approximately 3 percent between

TABLE A.4

INDICES OF TOTAL AGRICULTURAL PRODUCTION, FOODGRAINS OUTPUT, POPULATION AND GROSS PER CAPITA CALORIE AND PROTEIN SUPPLIES

Ethiopia 1964-1971; 1965 = 100

Year	Indices of Total Agricultural Production	Indices of Foodgrain Production	Indices of Population	Indices of Gross Per Capita Calorie Supply	Indices of Gross Per Capita Protein Supply
1964	97.9	98.0	98.3	100.0	100.0
1965	100.0	100.0	100.0	100.0	100.0
1966	102.2	102.1	102.0	100.2	100.4
1967	104.8	104.3	104.3	100.3	100.7
1968	107.9	107.6	106.7	101.2	101.6
1969	110.6	110.0	109.1	101.4	101.8
1970	113.7	117.8	111.6	101.9	102.6
1971	116.8	115.6	113.7	102.9	103.8

SOURCES: Computed by the author using data obtained from: Imperial Ethiopian Government, Central Statistical Office, Ethiopia: Statistical Abstract (Addis Ababa: CSO, 1966-1972); Calorie and protein conversion factors obtained from Imperial Ethiopian Government, Interdepartmental Committee on Nutrition for National Defence, Ethiopian Nutrition Survey (Addis Ababa, September, 1959).

1964 and 1971, an increase of less than 0.4 percent per year. However, this does not mean that actual calorie and protein intake increased by even that meagre amount. The index shown in Table A.4 is calculated on the basis of gross figures, so it is possible that the level of nutritional intake may actually have declined if allowances were made for net exports, seed, feed, waste, and industrial uses. Since in recent years the increase in agricultural output was obtained primarily by expanding the cultivated area rather than by increasing yield per hectare, which means that the share of output allocated for seed must have increased, and since industrial activity as well as exports have shown sharp increases, it seems reasonable to speculate that actual nutritional intake may have declined.

The conclusion that nutritional intake in Ethiopia may have declined over the past decade seems to be supported by the results of various food balance computations carried out at different intervals between 1958 and 1971 (Table A.5). Except for the study by the Ethiopian Nutrition Survey,[1] which used the combined techniques of family consumption studies, clinical diet analysis and the food balance method, the rest of the estimates were based strictly on food balance computation. Although the food balance technique is a very crude technique, the resulting estimates

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[1] Imperial Ethiopian Government, Interdepartmental Committee on National Defence, Ethiopian Nutrition Survey (Addis Ababa, September, 1959).

TABLE A.5

ESTIMATES OF DAILY PER CAPITA CALORIE INTAKE

IN ETHIOPIA, 1958-1971

Year	Estimated Amount of Calories Per Capita Per Day	Source of Estimate
1958	2.545.8	Interdepartmental Committee on Nutrition in Ethiopia[1]
1959-61	2,130.0	Economic Research Service, USDA[2]
1961-63	2,042.0	Foreign Economic Dev. Serv., USDA[3]
1964-66	2,152.0	FAO[4]
1964-71	1,884.5	Author[5]
1968	1,622.0	W.G. Eichberger[6]

SOURCES: [1] Imperial Ethiopian Government, Interdepartmental Committee on Nutrition for National Defence, Ethiopian Nutrition Survey (Addis Ababa, September, 1959).

[2] U.S. Department of Agriculture, Economic Research Service, Food Balances for 30 Countries in Africa and West Asia, 1959-61, ERS Foreign-119 (Washington, D.C.: USDA, 1961).

[3] U.S. Department of Agriculture, Foreign Economic Development Service, Foreign Training Division Cooperating with USAID, "The Problem of Bringing Population into Balance with Available Resources -- Food, Air, Water, Space, and Minterals" (Washington, D.C.: USDA, November, 1970). (Mimeographed.)

[4] U.N., Food and Agricultural Organization, Agricultural Commodity Projectsion, 1970-1970 (Rome: FAO, 1971).

[5] Computed by author using the food balance technique. The raw data was obtained from Imperial Ethiopian Government, Central Statistical Office, Ethiopia: Statistical Abstract, 1972 (Addis Ababa: CSO, 1972), pp. 37-43.

[6] E.G. Eichberger, "Food Production and Consumption in Ethiopia" (Addis Ababa: Ministry of Agriculture, May, 1968), p. 31. (Unpublished Study.)

nevertheless seem to provide a useful basis for observing trends in nutritional levels. The estimates of the daily average per capita calorie intake arrived at by the various independent studies seem to show a declining tendency in nutritional availability. One important conclusion that seems to emerge from these simple figures is the generally accepted view that increases in food supply in Ethiopia have not really kept up with the rate of population growth.

Some words of caution, however, appear to be in order. The food balance method is a very crude technique of measuring national nutritional levels. When this crudeness of technique is coupled with the paucity of data, there is no doubt that the margin of error can be wide and therefore can lead to misleading conclusions. Since in general nutritional requirements vary among sexes, age groups, and type of activity, and since a significant proportion of the Ethiopian people is in the younger age group (45.3 percent of the total population in 1972 was estimated to be below the age of 14),[1] the balance sheet method of computing national nutritional intake is likely to over-estimate the deficit in the average daily calorie intake of the population.

Actual figures and magnitudes aside, the undeniable fact is that there are serious inadequacies in calorie and

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[1] Imperial Ethiopian Government, Central Statistical Office, Ethiopia: Statistical Abstract, 1971, p. 27.

protein intake in the average daily Ethiopian diet. In recent years, the shortage was so acute that certain regions were hit by devastating famine conditions. Indeed, the food situation in Ethiopia is at a crisis level and the resolution of this crisis is the greatest challenge that the nation in general and Ethiopian agriculture in particular is now facing and, in all likelihood, will continue to face in the years and decades ahead.

If past records are any indication, however, Ethiopian agriculture, unless effectively mobilized, is unlikely to meet this challenge. In order to put Ethiopia's food problem in its proper perspective, it is essential to look at the food demand-supply situation by considering both the past trends and future prospects. The subsequent pages are an attempt in that direction.

Food Demand Projection for Ethiopia, 1970-1985

Economic theory suggests that the market demand for a commodity is determined by a specified set of factors. These factors include the price of the commodity itself, the price of related goods, the number of consumers, the level of consumer income, and tastes and preferences of consumers. In the empirical determination of demand, some of these factors pose special difficulties because data are not readily available or some factors, for example tastes and

preferences, cannot be quantified. Therefore, economic researchers often make simplifying assumptions to circumvent such limitations.

One of the simplifying assumptions often made in empirical demand study is that tastes and preferences remain constant. Generally speaking, as long as the time period under consideration is relatively short, this assumption does not pose a serious difficulty in demand projection. Once this assumption is made, it is easy to specify a quantitative demand model, which may be expressed in the following manner:

$$Q = N\, f(P_i \ldots P_n, Y) \tag{A.1}$$

where Q = total market demand for a commodity per unit of time,

N = number of consumers per unit of time,

P_i = price of commodity i per unit of time, $i=1,\ldots,n$,

n = the total number of commodities available in the market per unit of time,

Y = per capita consumer income per unit of time.

In the study of demand for food in a developing country, it is often necessary to make further simplifying assumptions owing to paucity of data and the nature of market structure. For instance, in Ethiopia, where a signifi-

cant non-monetized sector exists, absolute money prices are less important than relative barter terms of trade in projecting demand for food. But since price data, be they absolute or relative, are extremely hard to obtain in Ethiopia, it is necessary to assume that prices remain constant and base demand projections on the restricted variables of population and per capita income. The mathematical derivation of a demand projection model for food based on these two variables alone can be illustrated as follows:

$$Q = N\ f(Y, \overline{P}) \qquad (A.2)$$

where Q = total demand for food per unit of time,

N = population per unit of time,

Y = per capita income per unit of time,

$\overline{P}$ = food price index assumed to be constant.

Assume the implicit function (A.2) takes the specific form of a Cobb-Douglas function: $Q = N(kY^nP^e)$, where n and e along with k are unknown parameters. Through simple manipulation of this explicit Cobb-Douglas function, it can be shown that

$$\frac{dQ}{Q} = \frac{dN}{N} + n\ \frac{dY}{Y} + e\ \frac{dP}{P}\ . \qquad (A.3)$$

That is, the rate of change in food demand is equal to the rate of population growth, the rate of change of the proportion of income spent on food and the rate of change of prices. In this equation n and e are income and price elasticities of demand for food, respectively.

Since initially P is assumed to be constant, i.e., $\frac{d\overline{P}}{P} = 0$, equation (A.3) reduces to:

$$\frac{dQ}{Q} = \frac{dN}{N} + n\,\frac{dY}{Y} \tag{A.4}$$

Hence the rate of change of quantity demanded is the sum of the rate of change of population plus the income elasticity of demand multiplied by the rate of change of per capita income.

This model is, at best, a very naive model, but despite data and other limitations, it seems to provide reasonable estimates. According to this model, in order to obtain a rough estimate of quantity demanded at some future date, all one needs to know is the base year consumption level, the rate of population growth, income elasticity of demand for food and the rate of change of per capita income. These variables can be estimated fairly accurately for Ethiopia and this fact makes the present model more attractive than the more elaborate models whose highly detailed and massive data requirements cannot be met under existing conditions.

Given the above theoretical formulation then, the rate of change of demand for food in Ethiopia can be approximated if the rate of population growth, the income elasticity of demand for food and the rate of change of per capita income are known. It is, therefore, necessary to pay attention to these variables.

Rate of Population Growth in Ethiopia

The average annual population growth rate in Ethiopia over the last decade (1961-1970) was estimated at about 1.9 percent (Table A.1). This relatively low rate of growth was largely attributed to high mortality rates rather than to low rates of fertility. Certain inherent factors, however, seem to indicate that population growth will speed up considerably in the 1970's and 1980's. For instance, the growth rate had already climbed to 2.3 percent between 1969 and 1970.[1] Later estimates show that the population took a 2.4 percent jump between 1971 and 1972.[2] Indeed, there is every indication that the average annual growth rate for the present deacde will be in the order of 2.5 percent per year.

Among the indicators of future rates of growth are the age and sex structure of the population. The official

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[1] Imperial Ethiopian Government, Central Statistical Office, Ethiopia: Statistical Abstract, 1971, p. 26.

[2] *Ibid.*, 1972, p. 23.

population estimate for 1971 indicates that 55.7 percent of the population was 19 years of age or less, with an approximately 50:50 sex ratio. This means that the seeds for a more rapid rate of population growth in the coming two decades have already been sown. Furthermore, so far no official policy has been adopted to regulate the rate of population growth. Even the modest measures in family planning that have become a common feature of community development programs in many developing countries are conspicuously absent in Ethiopia. Therefore, in the foreseeable future, as improvements in health care and sanitation continue to reduce the mortality rate without any corresponding restraint on the fertility rate, the Ethiopian population will continue to expand at an accelerated rate.

The high rate of population growth will, no doubt, place an upward pressure on total demand for food. This pressure, however, is likely to be distributed unevenly between rural and urban areas. Currently, the urban population is estimated to be growing at the rate of 6.6 percent and is expected to double in 11 years.[1] The urban centers, therefore, constitute areas of strong potential demand for food.

The picture that emerges then is that there will be a strong upward pressure on demand for food as a result of rapid population growth in the years ahead. The rate of

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[1] Ibid.

growth in demand arising from population growth alone can be expected to be in the order of 2 to 2.5 percent per year in the 1970's and possibly the 1980's.

Per Capita Income

Per capita income in Ethiopia, expressed in 1961 dollars, increased at an annual average rate of 2.1 percent over the last decade (1961-1970, Table A.1). But national income is by no means evenly distributed in Ethiopia. There is a huge disparity in income distribution among regions and social classes.

Average personal incomes are much higher in the urban areas than in the rural areas. In general, most of the cash income, and hence, effective demand for food, is concentrated in the hands of the relatively small urban population. A 1969 study by Stanford Research Institute[1] revealed the following salient facts pertaining to per capita income in Ethiopia.

1. Urban per capita income averaged an estimated E $415 while rural per capita income averaged only an estimated E $107.
2. Urban per capita income is rising substantially faster than rural income -- 5.4 percent annually between 1962-67 compared with 0.5 percent.

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[1] A.R. Theody, Marketing of Grains and Pulses in Ethiopia, Report No. 16 (Menlo Park, California: Stanford Research Institute, 1969), p. 35.

3. Urban incomes are mostly monetized while rural incomes are mostly imputed values of subsistence consumption.
4. In both urban and rural areas, income distribution is exceedingly unequal.

Given these basic facts it is clear that the vast rural population has extremely limited purchasing power, and this lack of purchasing power, to a large degree, explains why nutritional intakes are very low and malnutrition is more endemic in the rural areas.

In more recent times, it has been increasingly recognized that it is a primary responsibility and moral obligation of government to see that every citizen is provided with the basic necessities of life, especially basic foodstuffs. The government, therefore, must either create conditions and policies whereby physically and mentally able individuals can be gainfully employed and earn a living, or it must institute massive redistributive and welfare schemes to ensure that everyone will have access to basic necessities. Indeed, a society that ignores this fundamental responsibility cannot remain viable in today's heightened social and political consciousness. It is in this light that the whole food and population problem in Ethiopia should be viewed.

In summary, per capita income in Ethiopia made an annual average gain of 2.1 percent over the last decade. It seems reasonable to expect this rate of growth to continue

into the next decade as well. But the impact of the rise in per capita income on demand for food will depend on the income elasticity of demand.

Income Elasticity of Demand for Food in Ethiopia

The level of family income has a profound effect on the quality and quantity of food consumed. It is a well established economic phenomenon (Engles law) that low income families spend a very high proportion of their income on food, but as income rises this proportion progressively declines. Changes in family income affect both the quantity and pattern of consumption. In general, the responsiveness of food demand to changes in the level of income is measured by the income elasticity of demand. According to Engles law, the income elasticity of demand for food as a whole is between 0 and 1 (i.e., demand for basic necessities is inelastic).

Since family incomes are very low in Ethiopia, one would normally expect a high (i.e., close to unity) income elasticity of demand for food. However, as development takes hold and incomes rise above the biological and sociological subsistence levels, demand elasticity can be expected to decline but always remain above zero for food as a whole.

The pattern of consumption also tends to change considerably with increases in income. As their income rises, families will tend to shift consumption from cereal and

starchy based diets to more proteinous and fatty diets such as meat and dairy products. Therefore, within the various food groups, it is possible that the elasticity for some products will decline below zero (inferior commodities) while for others it will be relatively high.

In Ethiopia, only a limited number of family consumption studies are presently available. But these do confirm the general suspicion that the income elasticity of demand for food is relatively high. The estimates available vary between 0.7 and 1.03 for food as a whole.[1] For the purpose of this study, however, an average figure of 0.8 has been adopted.

Using the above values for the variables in the demand projection model (equation (A.4)), one can determine some general future trends in the demand for food in Ethiopia. According to the model, demand for food in Ethiopia can be expected to increase at a rate of between 3.68 and 4.2 percent per year during the period 1970 to 1985. At an average annual growth rate of 4.2 percent, the 1985 demand for food in Ethiopia will be almost double that of the 1970 demand (Table 1.8).

The model is limited to domestic household demand and

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[1] For a discussion of rural and urban household consumption studies refer to: A.R. Theody, Marketing of Grains and Pulses in Ethiopia, pp. 35-39. See also: F.A.O., Agricultural Commodity Projections, 1970-1980, Vol. II (Rome: F.A.O., 1971), p. 194.

hence does not take into account industrial and export demands. Export sales, which almost exclusively are composed of farm products, increased at an annual rate of 4.6 percent between 1961 and 1970 (Table A.3). The trend is for continued strong export demand, particularly for such commodities as pulses and oilseeds. Anticipated industrial expansion and strong export demand will therefore impose additional heavy demands on farm output and resources.

In general, then, there will be a strong upward pressure on demand for farm commodities (foodgrains in particular) in Ethiopia in the years ahead. The main sources of this pressure will be the rapid rate of population growth and, to some extent, increases in per capita income. Industrial expansion and export demand from abroad will also continue to exert strong upward pressure on demand for farm commodities. Consequently assuming a high rate of population growth, the overall demand for food in Ethiopia can be expected to increase at a rate in excess of 4.2 percent per annum between 1970 and 1985.

This discussion has so far concentrated on only one side of the food picture. To complete the picture of the food problem in Ethiopia, one must look at the supply side also.

Food Supply Projection for Ethiopia, 1970-1985

Among the main factors that affect the total domestic supply of food in a given country at any given time are the price of food itself, the availability and price of production inputs, the level of technology, weather conditions, the expectation and preference of producers and government farm policy. Any systematic projection of the future supply of food therefore requires the accurate prediction of the future levels of these factors. Needless to say, some of the crucial variables, such as weather conditions and the rate of technological change, cannot be predicted with an acceptable degree of certainty even over a relatively short period of time. The prediction of future price levels is also equally risky even in situations where reliable data are available from past records. Given the paucity of data and the large number of unknowns in the Ethiopian agricultural production system, it does not seem advisable or practical to utilize elegant models to arrive at projected future levels of food supply. Nevertheless, some tentative estimates based on historical trends in the food production sector may prove helpful.

Past trends in agricultural production as a whole have not been satisfactory. In the 1960's, agricultural output increased at an average annual rate of 2.0 percent (Table A.1). However, the increase in the effective food

supply, that is, the average growth rate of the crop and livestock sector, for the same period was only 1.9 percent. Most of this increase was obtained through the expansion of croplands rather than through increases in yield. National average yields of practically all foodgrains, oilseeds and pulses showed hardly any increase between 1961 and 1970. During the same period, however, cropped area increased at an average annual rate of approximately 1.1 percent, up from about 9.0 million hectares to approximately 10.0 million hectares.[1]

The Third Five Year Plan (1968-1973) projected an annual growth rate of 3.1 percent, in value terms, for the agricultural sector as a whole during the plan period. The projection was based on the expected expansion of the peasant subsistence sector (1.8 percent) and the commercial farming sector (6.3 percent).[2] Among the measures planned to encourage production and provide incentives were the provision of commercial fertilizers at reasonable prices through the "minimum package program" and the improvement of the grain marketing structure. As it turned out, the Third Five Year Plan was thrown off course by unfavorable weather conditions and political upheaval, and it is not

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[1] Computed from data obtained from Imperial Ethiopian Government, Central Statistical Office, Ethiopia: Statistical Abstract, 1963 through 1971.

[2] Imperial Ethiopian Government, Third Five Year Development Plan, 1968-1973, p. 201.

known how much of the planned target was achieved. Nevertheless, it is widely regarded that the fertilizer program has been moderately successful at least in some parts of the country. More important, however, the direction set by the "minimum package program" seems to have resulted in substantial increases in crop yields in the foodgrain producing areas of Ethiopia.

In the final analysis it seems reasonable to expect that between 1970 and 1985 the new farm programs, including the "minimum package program" and the land reform program announced in March, 1975, may help increase the average annual growth rate of foodgrain production to between 2 and 3.5 percent. In this study supply projections have been made for selected food commodities for 1980 and 1985, assuming an average annual growth rate of 3.5 percent.

Demand-Supply Comparison

From the foregoing discussion, it is quite clear that in the foreseeable future projected demand for food in Ethiopia will exceed projected supply, assuming price remains constant at the 1970 level. It is estimated that demand for food will increase at a rate of 4.2 percent per year between 1970 and 1985, and at this rate of growth, the quantity of food that will be demanded in 1985 will be almost double that of the quantity demanded in 1970. The available evidence indicates that this level of growth in demand will

be sustained as rapid population growth, increasing urbanization, rising incomes, export sales and industrial expansion continue to put strong pressures on demand for farm commodities.

Food supply in Ethiopia, on the other hand, is not expected to grow by more than 3.5 percent per year over the period 1970-1985. From all indications, it appears that the actual average annual growth rate in food supply will be between 2 and 3.5 percent. However, even a 3.5 percent annual rate of growth would still result in substantial supply shortfalls by 1980, and if this rate continues unchanged up to 1985, the annual production will only meet about 85 percent of the 1985 demand (Table A.6). When comparing the demand-supply situation, then, the emerging picture is one of persistent excess demand over the next decade. Evidence of excess demand is already showing itself in soaring commodity prices and acute regional shortages. In all likelihood, therefore, it appears that the country will experience a period of prolonged food crises unless substantial investment is made in boosting food production in the shortest possible time.

This gloomy prediction is shared by several authors. Assefa Bequele and Eshetu Chole,[1] for instance, attributed the lag in Ethiopia's economic development to the slow pace

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[1] Assefa Bequele and Eshetu Chole, <u>A Profile of the Ethiopian Economy</u>, p. 34.

TABLE A.6

DEMAND-SUPPLY PROJECTIONS OF SELECTED FOOD COMMODITIES, ETHIOPIA, 1970-1985

Type of Commodity	1970			1980			1985		
	Demand	Supply	D-S	Demand	Supply	D-S	Demand	Supply	D-S
				(In '000's of Metric Tons)					
Foodgrains									
Barley	1,529.9	1,529.5	0	2,427.1	2,157.5	269.5	3,024.6	2,562.4	462.2
Maize	949.0	939.0	10.1	1,473.8	1,324.6	149.2	1,836.6	1,573.2	263.4
Sorghum	1,083.4	1,066.8	16.6	1,682.5	1,504.8	177.7	2,096.7	1,787.3	309.4
Teff	1,403.0	1,362.2	40.8	2,178.8	1,921.5	257.3	2,715.2	2,282.2	43.3
Wheat	844.4	839.5	4.9	1,311.3	1,184.2	127.1	1,634.2	1,574.0	60.2
Millet	160.8	155.4	5.4	249.7	219.2	30.5	311.2	260.4	50.8
Oilseeds									
Groundnuts	23.4	24.2	-0.8	36.3	34.1	2.2	45.3	40.5	4.8
Linseed	64.9	64.4	0.5	100.8	90.8	10.0	125.6	107.9	17.7
Noog	270.2	268.2	2.0	419.6	378.3	41.3	522.9	449.3	73.6
Safflower	35.2	36.2	-1.0	54.7	51.1	3.6	68.1	60.6	7.5
Sesame	72.5	81.3	-8.8	112.6	114.7	-2.1	140.3	136.2	4.1
Pulses									
Chick Peas	193.6	191.2	2.4	300.6	269.7	30.9	374.7	320.3	54.4
Field Peas	132.1	129.4	2.7	205.1	182.5	22.6	255.6	216.8	38.8
Haricot Beans	75.6	74.6	1.0	117.4	105.2	12.2	146.3	125.0	21.3
Lentils	111.3	110.6	0.7	172.8	156.0	16.8	215.4	185.3	30.1
Horsebeans	144.0	144.9	-0.9	223.6	204.4	19.2	278.7	242.8	35.9

TABLE A.6 (CONTINUED)

Type of Commodity	1970			1980			1985		
	Demand	Supply	D-S	Demand	Supply	D-S	Demand	Supply	D-S
				(In '000's of Metric Tons)					
Fruits and Vegetables									
Fruits	84.5	85.4	-0.9	131.2	120.5	10.7	163.5	143.1	20.4
Berbere (Pepper)	103.9	102.2	1.9	161.4	144.2	17.2	201.1	171.2	29.9
Potatoes	167.8	165.1	2.7	250.6	232.9	27.7	324.7	276.6	48.1
Yam	264.3	258.1	6.2	410.4	364.1	46.3	511.5	432.4	79.1
Misc. Vegetables	268.1	264.4	3.7	416.4	373.0	43.4	518.8	443.0	75.8
Animal Products									
Beef	291.3	292.9	-1.6	452.4	413.2	39.2	563.7	490.7	73.0
Mutton	50.3	49.1	1.2	78.1	69.3	8.8	97.3	82.2	15.1
Goat Meat	48.8	47.1	1.7	75.8	66.4	9.4	94.4	78.9	15.5
Poultry	56.3	54.9	1.4	87.4	77.4	10.0	108.9	92.0	16.9
Milk and Dairy Products	624.8	612.9	11.9	970.3	864.6	105.7	1,209.2	1,026.8	182.4
Eggs	67.9	65.8	2.1	105.4	92.8	12.1	131.4	110.2	21.2

SOURCE: Computed by author using data from Imperial Ethiopian Government, Central Statistical Office, Ethiopia: Statistical Abstract, 1972 (Addis Ababa: CSO, 1972), pp. 37-43.

and backwardness of agriculture. They particularly pointed out the critical state of the food supply and indicated that food production would have to increase by 4.5 percent per year if the country were to raise the per capita daily calorie intake from 1,622 calories in 1965 to 2,300 calories in 1972. In retrospect, the records show that food output increased by only 1.9 percent per year during that period.

Clarence J. Miller and others, in their report on "Production of Grains and Pulses in Ethiopia,"[1] expressed serious reservation about the country's ability to remain self-sufficient in food production in the 1970's and 1980's. They specifically stated that Ethiopia has been barely self-sufficient in cereal grains since the mid-1950's and that they seriously question the country's ability to meet the grain requirements of an expanding population during the coming decades unless production is materially increased.

Essentially the same concern was expressed by the Inter-Ministerial Committee on Regional Aspects of National Planning in Ethiopia in its 1967 report.[2] Based on analysis of data on food production and population, the Committee concluded that significant portions of the country have

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[1] Clarence J. Miller, et al., Production of Grains and Pulses in Ethiopia, Report No. 10 (Menlo Park, California: Stanford Research Institute, 1969), p. 1.

[2] Imperial Ethiopian Government, Ministry of Planning and Development, Regional Aspects of National Planning in Ethiopia, Part I (Addis Ababa: Ministry of Planning and Development, 1967), pp. 29-35.

serious food deficits and that the national food intake is too inadequate from the calorie and protein points of view.

A more recent study by Blakeslee, Heady and Framingham[1] predicts that there will be a significant excess demand for major food products in North Africa in 1980 and 2000 even under the assumption of low population growth rates and constant per capita income unless production is stepped up substantially. They summarize the results of their analysis in the following terms:

> The summary of the projections for North Africa can be brief. Present rates of agricultural production are less than necessary to meet almost any foreseeable pattern of demand, and continuation of past production trends would result in steadily worsening production demand comparisons throughout the period under study.[2]

Many similar instances could be cited here, but in the interest of brevity, the above will suffice. While the evidence clearly indicates that Ethiopia will continue to face a prlonged period of food shortages, it is possible that the dire consequences that follow from such a state of affairs may not be fully apparent to policy makers so as to elicit immediate corrective action. It is therefore important to illustrate some of the likely consequences that will result from persistent food shortages.

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[1] Leroy L. Blakeslee, Earl O. Heady, and Charles F. Framingham, World Food Production, Demand and Trade (Ames, Iowa: Iowa State University Press, 1973), p. 163.

[2] Ibid.

The implication of prolonged food deficits for national welfare and economic development are far reaching. At the outset, it should be realized that the adverse impacts of food scarcity will be felt unequally among regions, social classes and even various age groups within the family. Food shortages often result in immediate disasters in those rural areas where deficits normally exist. The peasantry living in these regions become afflicted with widespread destitution, famine and subsequent mass deaths, the moral and ethical dimensions of which are beyond description.

Food scarcities also play havock with general economic stability and stifle economic development. For an economy such as Ethiopia's, one almost entirely based on subsistence agriculture, any perturbation in this sector will immediately be felt throughout the economy as a whole. A food crisis in Ethiopia, therefore, will inevitably lead to a general economic crisis and thereby compound the difficulties of economic development.

An ample supply of food available to the population at reasonable prices is a prerequisite for economic development. It is often difficult, if not impossible, to achieve sustained development in a nation laboring under widespread scarcities of staple commodities and ever rising food prices. Given the circumstances of the Ethiopian economy, with its great dependence on traditional agriculture and limited capacity to import food from abroad, a poor performance in

domestic food production imposes a severe constraint on economic development.

While the consequences and implications of food scarcity for economic development are very broad, they more specifically manifest themselves in such ways as reduced or impaired labor productivity, depleted foreign exchange earnings, reduced industrial activity and rising unemployment. These points, however, do not exhaust all the diverse ways in which food shortages can impair development and hence perpetuate the vicious circle of poverty among the population. Needless to say, food scarcity adversely affects the entire range of human activity. The provision of complete and adequate food supplies, therefore, is not only a measure of development in itself but is also a means to further growth and progress.

While the food problem undoubtedly stands out as the problem of highest national priority in Ethiopia, the problem of providing employment for the rapidly increasing labor force seems to be equally urgent. There is widespread unemployment and underemployment in Ethiopia and the unemployment rate may be expected to rise as the population increases in the years ahead. The food and unemployment problems, therefore, are the "twin" problems that require urgent corrective action if the well-being of the Ethiopian people is to be improved.

APPENDIX B

Steps in Public Project Development

Normally, there are a certain number of necessary steps that must be followed when developing a public investment project. Assuming that a clear and valid need for the project has been established, the project must pass at least five tests before it can be seriously considered for investment (Figure B.1). These tests are essential because they help to discriminate between those projects that have a high probability of being viable over the long run and those that have little or no chance of success.

The first of these tests is the technical feasibility of the project. Before its construction can even be contemplated, the project must be shown to be technically feasible and structurally capable of producing the goods and services it is intended to produce at a specified level of efficiency. In other words, the project must be sound and viable from the engineering point of view.

The second test is that of economic feasibility. Not all technically feasible projects are economically feasible as well. The test of economic feasibility is passed if the present value of social benefits resulting from the project exceeds the present value of social costs. But in the face of budget constraints, not all projects with positive net present values can be constructed. Of all the projects that are economically feasible, perhaps only one, or at best, a few, can yield maximum returns to a given budget

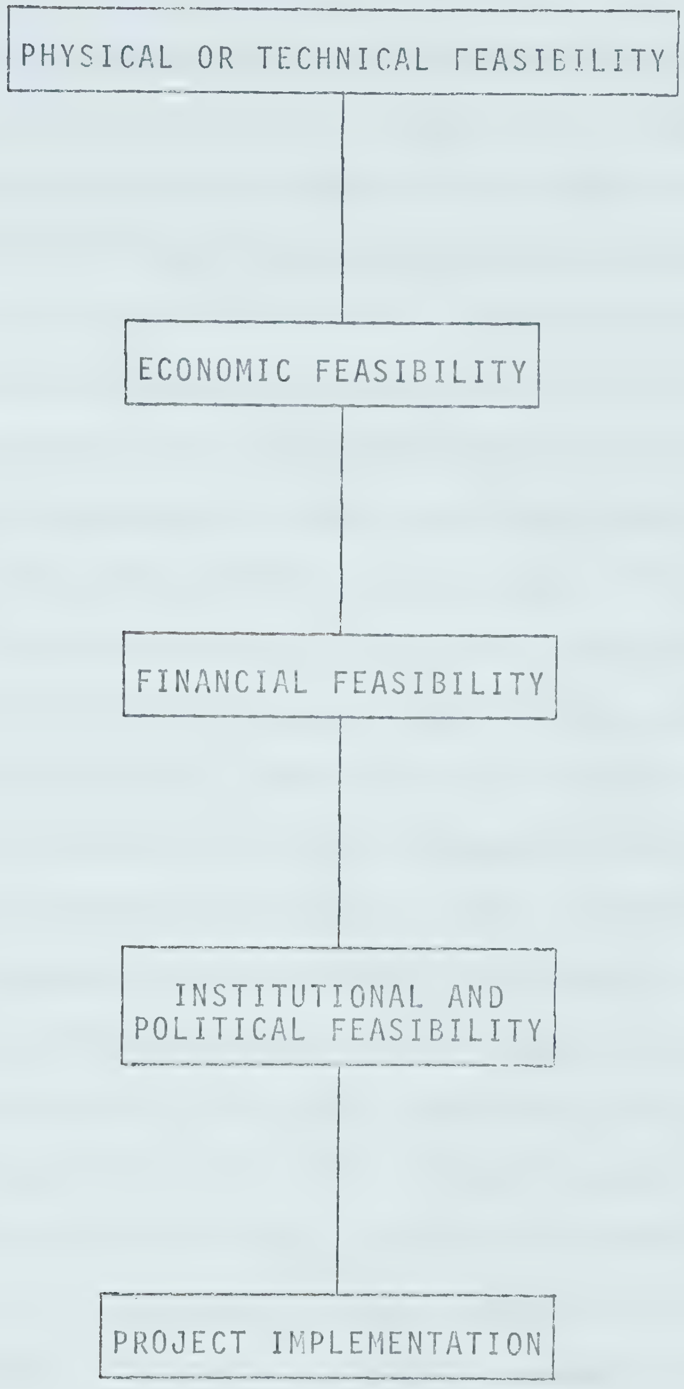

FIGURE B.1

STEPS IN PUBLIC PROJECT DEVELOPMENT

allocation at a given period of time.

Financial feasibility is the third test that is applicable to public project evaluation. A proposed project incurs costs not only during the initial period of construction but also throughout its productive life. Although a major part of the cost involves the construction cost, the project requires annual expenditures for operation, maintenance and replacement over its economic life. The public decision-making entities must decide how these costs are to be paid, whether or not the initial investment costs are to be reimbursed, and, if so, how much of it is to be repaid, who should pay it and how the repayment is going to be collected. These problems become particularly complex if the general rule that payment should be made in proportion to benefits derived is to be applied. The social benefits accruing from a project, as a general rule, are so widely distributed throughout the economy that seldom if at all can they be traced to the final point of incidence. Although there are certain immediately identifiable beneficiaries of the project, it would be unfair to expect them to bear all the costs since they do not derive the entire benefits. Financial analysis attempts to resolve these and similar matters and makes adequate provisions to ensure that the necessary funds can be made available not only to construct the project but also to operate and maintain it over its productive life.

The final test for a project is its institutional

feasibility. This refers to the political and social acceptability of the project. The final decision regarding a project lies within the political process, and its success in the long run largely depends on the willingness and cooperation of the people who will be directly affected by it.

If the proposed project is politically and socially feasible, the final act is to implement it. How the project is implemented, of course, will determine whehter it will fail or succeed in achieving its goal. Important as it is, the planning exercise alone cannot ensure success. Plans must be effectively and efficiently implemented if their stated goals are to be achieved. Managerial talents and skills are, therefore, particularly crucial factors in project implementation. The search for competent managers, i.e., those special breeds of people who have the ability to organize, control and efficiently operate an organization, should be part of the project planning process.

APPENDIX C

TABLE C.1

AVERAGE ANNUAL RAINFALL AND ALTITUDE OF SELECTED STATIONS IN ETHIOPIA

	Altitude (Meters)	Average Rainfall (mm)	No. of Years in Average
Addis Ababa	2,408	1,153.3	21
Asmara	2,325	497.0	29
Assab	11	53.1	21
Bahirdar	1,802	1,490.9	10
Combolcha	1,903	1,078.5	19
Debre Marcos	2,509	1,381.6	18
Debre Zeit	1,850	869.2	21
Dire Dawa	1,160	640.1	19
Gore	2,002	2,506.1	19
Jimma	1,740	1,509.1	15
Massawa	5	184.8	21
Nacfa	1,676	231.5	18
Wonji	1,500	814.5	21

SOURCE: Imperial Ethiopian Government, Central Statistical Office, Ethiopia: Statistical Abstract, 1972 (Addis Ababa: Central Statistical Office, 1972).

TABLE C.2

MANPOWER COSTS IN ETHIOPIA

Category	Wage Level
	(In 1970 Ethiopian Dollars)
Farm Manager	1,250/month
Foreman	500/month
Skilled Mechanics	6.00/day
Tractor Operators	5.00/day
Unskilled Workers	
Oxen Plowing	1.75/day
Weeding-Thinning	1.50/day
Harvesting	
Cotton	0.05/kilogram
Maize	1.50/quintal
Grains	1.50/quintal
Oilseeds	1.50/quintal
Seeding	1.50/day
General	1.25/day
Clerical	5.00/day

SOURCES: C.F. Miller, et al., Systems Analysis Methods for Ethiopian Agriculture (Menlo Park, California: Stanford Research Institute, 1968); and M.E. Quenemoen, Potential Returns from Commercial Farming Systems in Three Areas of Ethiopia (Dire Dawa: H.S.I.U. College of Agriculture, 1968).

TABLE C.3

LABOR PERFORMANCE COEFFICIENTS UNDER TRADITIONAL PRACTICES IN ETHIOPIA

	Man-Days of Labor/Hectare		
Operation	Cereals	Oilseeds	Pulses
Oxen Plowing	4	4	4
Broadcasting and Plowing Seed Under	2	2	2
1st Weeding and Cultivation	18-24	18-22	--
2nd Weeding	12-20	12-18	--
Cutting and Stalking	8-16	10	10
Threshing and Cleaning	5	4	4
Bagging, Transporting and Storing	2	2	2
Irrigation	25-35	25-35	25-35

SOURCES: L.F. Miller and T. Makonnen, Organization and Operation of Three Ethiopian Case Farms, Exp. Station Bulletin No. 35 (Dire Dawa: Imperial Ethiopian College of Agriculture and Mechanical Arts, 1965); and T. Makonnen, "Interregional Competition in Ethiopian Agriculture" (Unpublished Ph.D. Thesis, University of Alberta, 1973).

TABLE C.4

RATE OF MACHINERY PERFORMANCE IN ETHIOPIA

(One Tractor and Equipment)

Type of Operation	Highland Heavy Clay Soils	Lowland Sandy to Sandy Loam Soils
Plowing	2.5 ha./8 hr.	2.9 ha./8 hr.
1st Discing	5.0 ha./8 hr.	6.0 ha./8 hr.
2nd Discing	8.0 ha./8 hr.	10.0 ha./8 hr.
Making Ditches	32.0 ha./8 hr.	33.0 ha./8 hr.
Ridging	8.0 ha./8 hr.	9.0 ha./8 hr.
Threshing	35.0 quintals/8 hr.	35.0 quintals/8 hr.

SOURCES: C.F. Millet, *et al.*, *Systems Analysis Methods for Ethiopian Agriculture* (Menlo Park, California: Stanford Research Institute, 1968); and M.E. Quenemoen, *Potential Returns from Commercial Farming Systems in Three Areas of Ethiopia* (Dire Dawa: H.S.I.U., College of Agriculture, 1968).

TABLE C.5

CROP HANDLING COSTS

(Crop Handling Costs)

				Total	
Crop	($/sack)	($/sack)	($/sack)	$/sack	$/100 kg.
		(In 1970 Eth. Dollars)			
Cotton	0.50	0.20	0.20	0.90	1.12
Sorghum	1.35	0.20	0.25	1.80	1.80
Maize	1.35	0.20	0.25	1.80	1.80
Grains	1.45	0.30	0.25	2.00	2.00
Oilseeds	1.50	0.30	0.25	2.05	2.05
Pulses	1.35	0.20	0.25	1.80	1.80

SOURCE: C.F. Miller, *et al.*, *Systems Analysis Methods for Ethiopian Agriculture* (Menlo Park, California: Stanford Research Institute, 1968).

TABLE C.6

FERTILIZER PRICES AND APPLICATION COSTS

		Price		Cost of Application/ha.	
Item	Type	$/Metric Ton	$/kg of Element	Manual	Mechanical
		(In 1970 Eth. Dollars)			
Urea	4690N	250	0.90	9.00	6.30
Triple Superphosphate	40-42% P_{205}	235	0.88	9.00	6.30
Sulfate of Potash	50% K, 16% S	220	0.74	9.00	6.30

SOURCE: Computed from data obtained from Stanford Research Institute and fertilizer dealers in Addis Ababa.

TABLE C.7

INSECTICIDE PRICES AND APPLICATION COSTS

Chemical	Use	Rate of Application	Price Per kg.	Cost of Application/ha. Aerial Spraying	Tractor-boom Spraying	Manual Spraying
				(In 1970 Eth. Dollars)		
Sevin	Bollworms	2 kg/ha.	7.00	3	6.65	7.75
D.D.T.	Armyworms, Jassid	5 l/ha.	1.00	3	6.65	7.75
Endrin	General	4 l/ha.	3.60	3	6.65	7.75
Malathion	Aphids, Mites, Whitefly	3 l/ha.	3.00	3	6.65	7.75
Agrocide	Soil Pesticide	50 kg/ha.	0.45	3	6.65	7.75

SOURCE: Computed from data obtained from Stanford Research Institute and Pesticide dealers in Addis Ababa.

TABLE C.8

MACHINERY AND EQUIPMENT COSTS PER HOUR OF USE

Implement	Description	Life (Years)	Average Annual Use (Hours)	Total Life (Hours)	Retail Price	Cost Per Hour of Use: Capital Recovery Factor*	Repairs	Fuel and Oil	Total
						(In 1970 Eth. Dollars)			
Crawler Tractor	230 hp. Cat D-8	10	800	8,000	60,000	12.20	11.25	7.28	30.73
Wheel Tractor	55-65 hp.	10	800	8,000	9,500	1.93	1.76	2.94	6.63
Wheel Tractor	65-75 hp.	10	800	8,000	10,500	2.14	2.15	3.51	7.80
Disc Plow	3-4 Furrows	15	200	3,000	1,700	1.12	0.87	--	1.99
Mouldboard Plow	3-4 Furrows	15	200	3,000	1,900	1.25	0.96	--	2.21
Disc Harrow	Tandem - 24 Discs	10	150	1,500	2,350	2.55	1.35	--	3.90
Wide Level Disc	24 Discs	10	400	4,000	4,600	1.87	1.33	--	3.20
Cultivator	4 Row	10	300	3,000	3,250	1.77	0.92	--	2.69
Rotary Tiller	Power Take-Off	10	300	3,000	4,500	2.45	2.05	--	4.50
Planter	4 row	10	100	1,000	2,900	4.73	2.52	--	7.25
Combine	12 Ft. Cut Self Prop.	10	200	2,000	30,000	24.45	12.00	8.55	45.00
Hay Baler	Power Take-Off	10	200	2,000	8,500	6.97	3.66	--	10.63
Drill	Grain & Fertilizer	10	200	2,000	4,000	3.26	2.24	--	5.50
Ditcher	Heavy Duty	10	150	1,500	750	0.81	0.44	--	1.25
Mower	7 Ft. Swath	10	150	1,500	1,200	1.37	1.09	--	2.40
Trailer	5 Ton	10	400	4,000	4,000	1.63	1.37	--	3.00
Trailer	3 Ton	10	400	4,000	2,250	0.92	0.79	--	1.71
Chisel Plow	Subsoiler	10	200	2,000	1,800	1.47	0.78	--	2.25
Land Leveler	Wheel Tractor Towed	10	150	1,500	2,500	2.71	1.88	--	4.59
Land Plane	Crawler Tractor Towed	10	150	1,500	6,500	7.06	4.85	--	11.91
Rotary Cutter	Power Take-Off	10	150	1,500	2,600	2.83	1.93	--	4.76
Power Spray Boom	Tractor Towed	10	200	2,000	1,800	1.47	1.23	--	2.70
Knapsack Sprayer	Back Pack	5	400	2,000	250	0.17	0.19	0.42	0.78
Pumping System	Diesel Power, 300 m^3/hr. with Piping	10	2,500	25,000	8,000	0.52	0.64	1.37	2.53
Pumps & Motors	850 m^3/hr.	10	2,500	25,000	15,000	0.98	0.67	1.89	3.54
Vehicle	4 WD Pickup	10	1,800	18,000	11,800	1.07	8.90	2.69	12.66

* Capital recovery factor = $\frac{i(1+i)^n}{(1+i)^n - 1}$, where i = 10%, n = life of equipment.

SOURCE: C.F. Miller, et al., Systems Analysis Methods for Ethiopian Agriculture (Menlo Park, California: Stanford Research Institute, 1970); and M.E. Queremoun, Potential Returns from Commercial Farming Systems in Three Areas of Ethiopia (Dire Dawa: H.S.I.U. College of Agriculture, 1968).

APPENDIX D

TABLE D.1

OPTIMAL TEN YEAR CROP MIX AND LAND ALLOCATION PLAN.[1] STRATEGY I: ANIMAL POWERED OPERATION, MEGECH RIVER PROJECT

	1st Year	2nd Year	3rd Year	4th Year	5th Year	6th Year	7th Year	8th Year	9th Year	10th Year
					(In Hectares Per Crop Per Year)					
Barley	118.00	141.60	184.08	350.89	453.15	526.45	623.63	700.39	740.47	814.57
Horsebean	15.50	18.60	32.32	42.02	54.63	68.29	83.23	99.88	119.86	131.85
Lentils	25.75	30.90	47.08	60.20	78.26	97.82	120.32	114.38	187.69	206.46
Linseed	13.25	15.90	29.08	37.80	49.14	16.42	75.55	90.66	117.86	129.65
Maize	90.00	160.00	292.41	389.93	502.91	608.40	648.33	778.00	833.60	916.96
Noogseed	11.50	13.80	29.56	38.43	49.96	62.45	76.81	92.27	189.95	208.94
Potatoes	83.00	99.60	189.62	246.51	320.46	380.58	468.97	562.76	596.15	638.62
Sorghum	101.00	291.70	475.77	516.91	611.17	703.96	765.87	857.34	985.94	1,083.13
Teff	48.00	198.00	237.60	348.99	403.69	504.61	620.67	682.74	755.54	831.09
Wheat	83.00	207.90	249.48	324.32	421.62	520.02	639.62	703.58	773.94	928.73
Total	589.00	1,178.00	1,767.00	2,356.00	2,945.00	3,534.00	4,123.00	4,712.00	5,301.00	5,890.00

[1] Solution yielded by a ten year recursive programming model.

SOURCE: Computed by author.

TABLE D.2

OPTIMAL TEN YEAR CROP MIX AND LAND ALLOCATION PLAN,[1] STRATEGY II: SEMI-MECHANIZED OPERATION, MEGECH RIVER PROJECT

	1st Year	2nd Year	3rd Year	4th Year	5th Year	6th Year	7th Year	8th Year	9th Year	10th Year
					(In Hectares Per Crop Per Year)					
Barley	78.00	101.40	131.82	191.14	272.28	394.81	473.77	568.52	682.22	818.66
Fenugreek	11.00	14.30	18.59	26.96	40.44	58.64	70.37	84.44	101.33	121.60
Horsebeans	17.00	22.10	28.73	41.66	60.41	87.59	105.11	126.13	151.36	181.63
Lentils	17.00	23.00	29.99	43.49	63.06	91.44	109.73	131.68	158.02	189.62
Maize	110.00	309.00	528.24	657.37	722.00	736.98	841.47	900.97	962.46	983.29
Noogseed	29.00	37.70	49.01	71.06	103.04	149.41	179.29	215.15	258.18	309.82
Pepper	7.00	9.10	11.83	17.15	24.87	36.06	43.27	51.92	62.30	74.76
Potatoes	83.00	99.60	129.48	187.75	272.24	394.75	473.70	568.44	682.13	718.56
Sorghum	61.00	337.90	548.24	697.37	762.69	796.97	881.47	930.97	982.46	1,001.29
Teff	58.00	76.40	99.32	144.01	208.81	302.77	363.32	435.98	523.18	627.82
Wheat	118.00	145.50	191.75	273.04	403.16	484.58	581.50	697.80	737.36	862.96
Total	589.00	1,178.00	1,767.00	2,356.00	2,945.00	3,534.00	4,123.00	4,712.00	5,301.00	5,890.00

[1] Solution yielded by a ten year recursive programming model.

SOURCE: Computed by author.

TABLE 9.3

OPTIMAL TEN YEAR CROP MIX AND LAND ALLOCATION PLAN,[1] STRATEGY III: FULLY MECHANIZED OPERATION, MEGECH RIVER PROJECT

	1st Year	2nd Year	3rd Year	4th Year	5th Year	6th Year	7th Year	8th Year	9th Year	10th Year
					(In Hectares Per Crop Per Year)					
Barley	118.00	118.00	129.80	142.78	171.34	188.47	207.32	228.05	250.86	275.95
Fenugreek	10.00	13.00	14.30	15.73	8.88	20.77	22.85	25.14	27.65	30.56
Horsebeans	15.00	24.37	26.81	29.49	35.39	38.93	42.82	47.10	51.81	56.99
Lentils	15.00	35.00	38.50	42.35	50.82	55.90	61.49	67.64	74.40	81.84
Linseed	29.00	49.75	57.72	63.49	76.19	83.81	92.19	101.41	111.55	122.71
Maize	23.00	260.50	700.25	1,182.38	1,538.28	1,986.61	2,420.87	2,839.65	3,241.41	3,625.31
Noogseed	29.00	59.25	65.18	71.70	85.20	93.72	103.09	113.40	134.74	137.21
Pepper	7.00	7.00	8.00	9.00	10.00	11.00	12.10	13.31	14.64	15.04
Potatoes	80.00	87.38	96.12	105.73	126.80	139.57	153.53	168.88	185.77	204.34
Sorghum	87.00	187.73	215.70	347.27	416.72	458.39	504.23	554.65	610.12	671.13
Teff	58.00	148.02	162.83	179.10	224.92	236.41	260.05	286.06	314.67	346.14
Wheat	118.00	188.00	151.80	166.98	200.38	220.42	242.46	266.71	293.38	322.78
Total	539.00	1,178.00	1,767.00	2,356.00	2,945.00	3,534.00	4.123.00	4,712.00	5,301.00	5,890.00

[1] Solution yielded by a ten year recursive programming model.

SOURCE: Computed by author.

TABLE D.4

OPTIMAL TEN YEAR CROP MIX AND LAND ALLOCATION PLAN,[1] KESEM RIVER PROJECT

	1st Year	2nd Year	3rd Year	4th Year	5th Year	6th Year	7th Year	8th Year	9th Year	10th Year
					(In Hectares Per Crop Per Year)					
Cotton	202.50	348.06	403.88	472.25	556.00	658.69	769.29	938.26	1,126.86	1,155.00
Groundnuts	93.00	218.58	251.18	292.76	345.77	413.35	499.52	609.39	749.48	830.00
Maize	51.75	173.57	306.14	353.11	520.88	788.64	899.67	963.12	1,156.62	1,280.00
Onions	84.00	95.62	108.84	132.92	241.03	260.53	289.73	308.01	346.77	369.50
Potatoes	56.50	68.34	175.22	299.97	220.91	246.24	286.88	313.94	368.76	413.00
Sorghum	49.00	166.05	289.04	320.02	461.79	528.39	593.94	696.30	634.21	720.00
Wheat	28.25	59.78	160.70	383.97	478.62	494.16	588.92	690.98	702.30	882.50
Total	565.00	1,130.00	1,695.00	2,260.00	2,825.00	3,390.00	3,955.00	4,520.00	5,085.00	5,650.00

[1] Solution yielded by a ten year recursive programming model.

SOURCE: Computed by author.